

# Overview of Bristol Bay Red King Crab Model

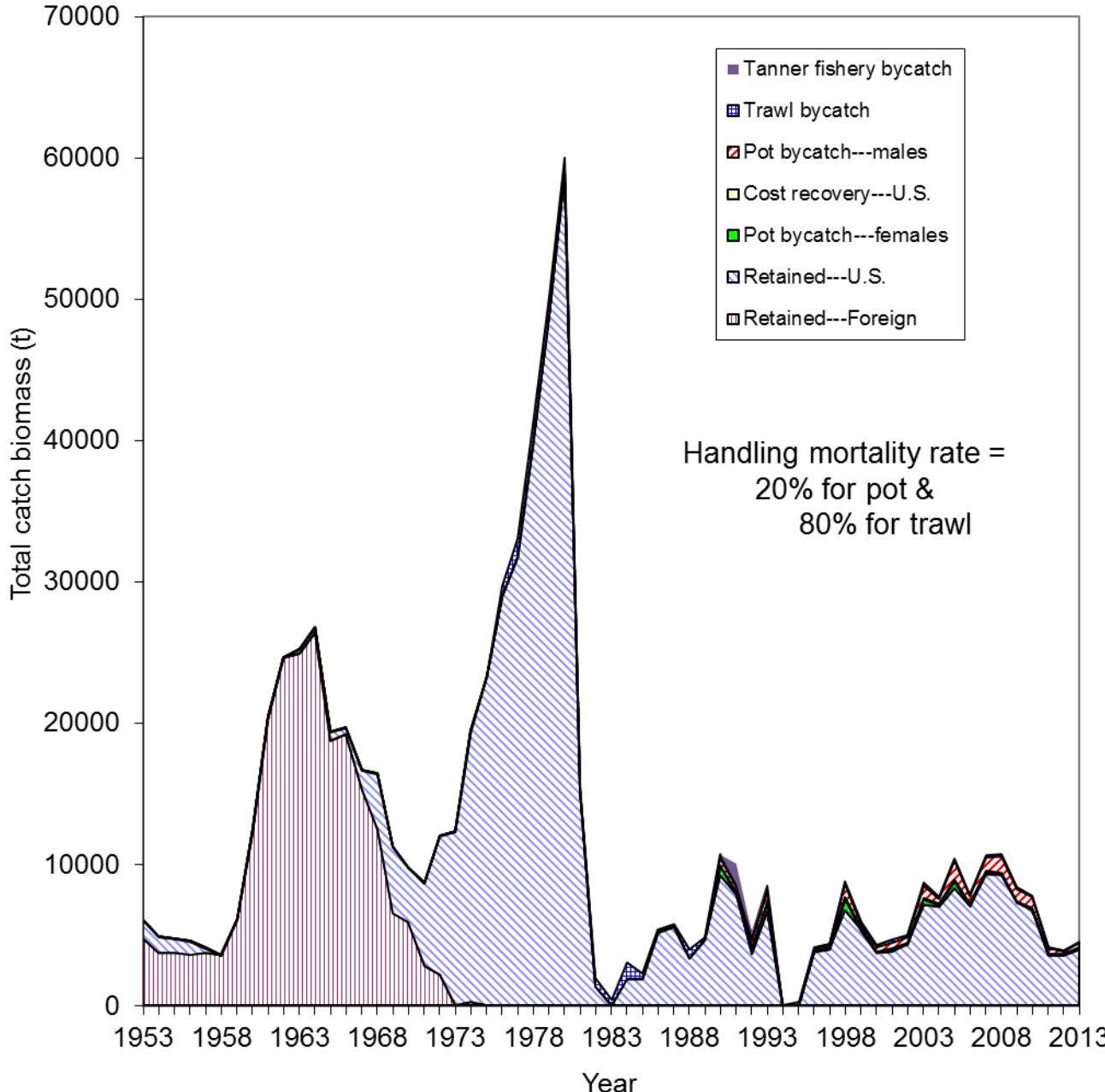
Jie Zheng and M.S.M. Siddeek  
ADF&G, Juneau

# Data

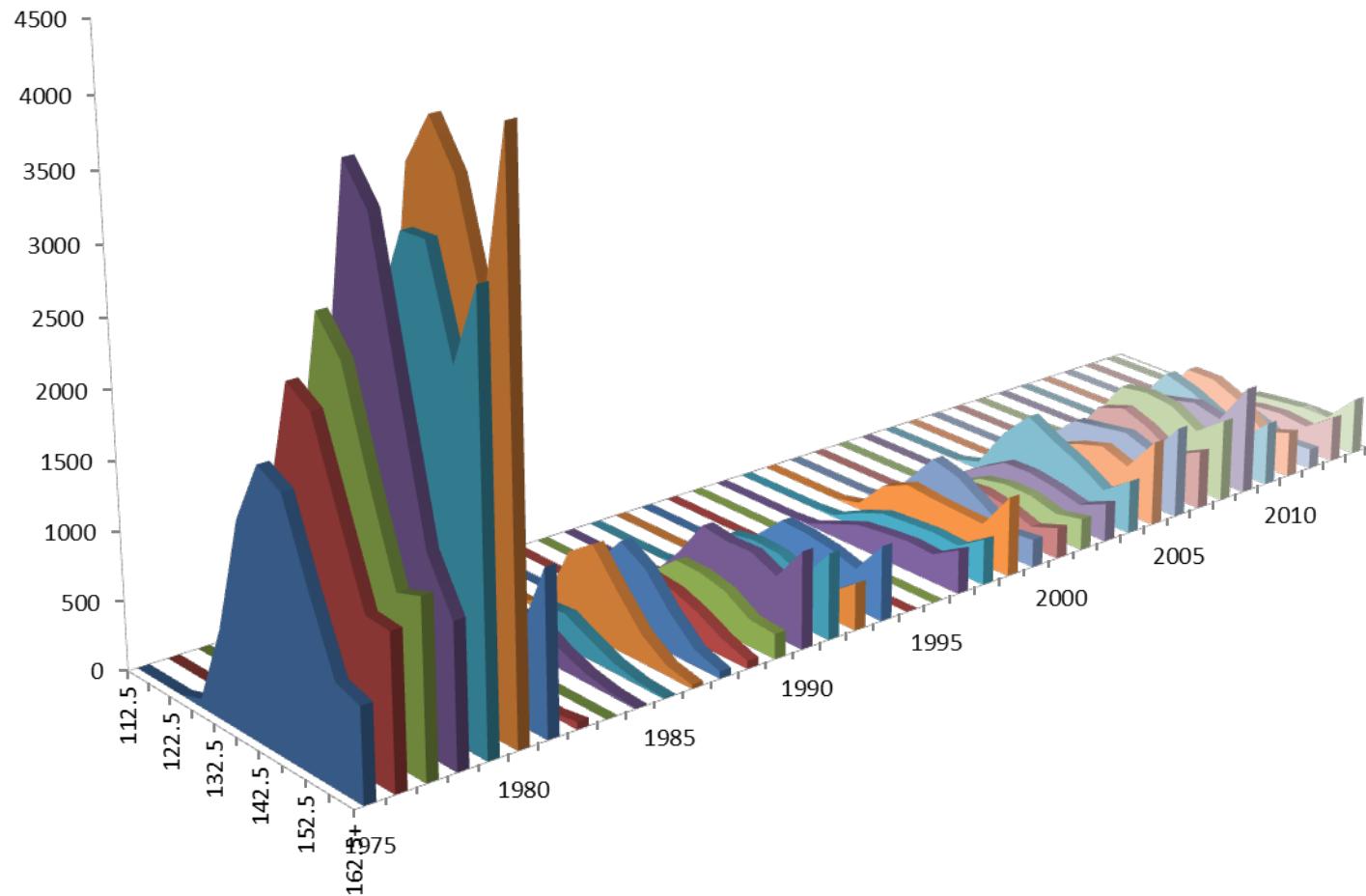
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- Catch data by sex and size
  - Retained catch and CPUE (1975-2013)
  - Bycatch
    - Directed pot (1990-2013)
    - Tanner crab fishery (1991-1993, 2013)
    - Groundfish trawling (1976-2013)
- Survey data
  - Summer trawl survey (1968-2014)
  - BSFRF survey data (2005, 2007-2008)

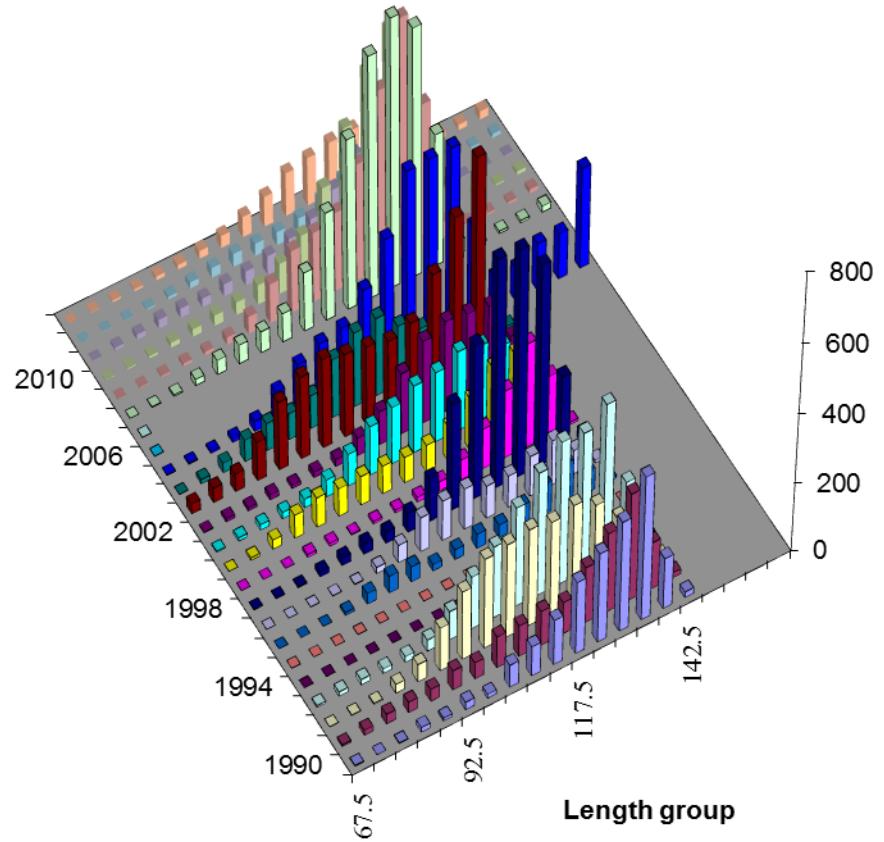
## Historical catch of Bristol Bay red king crab



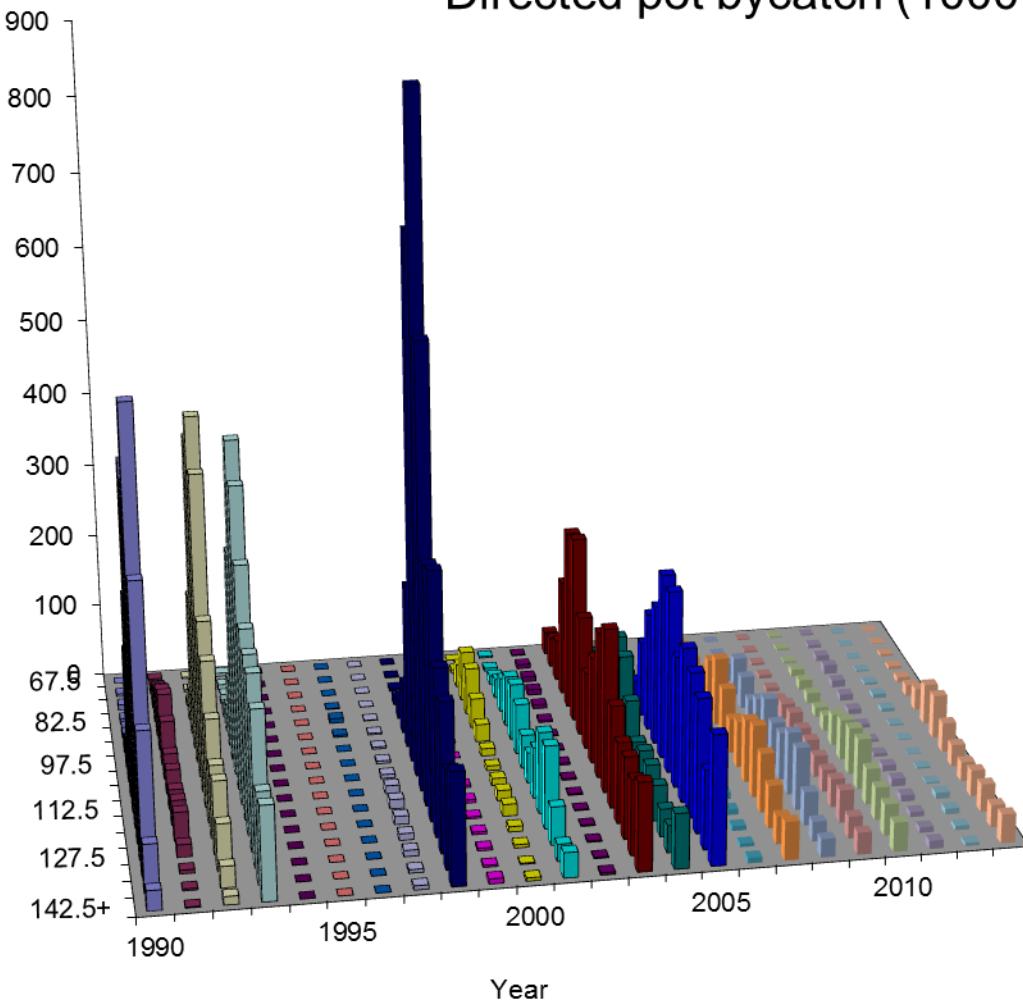
Number of retained catch (1000 crabs)



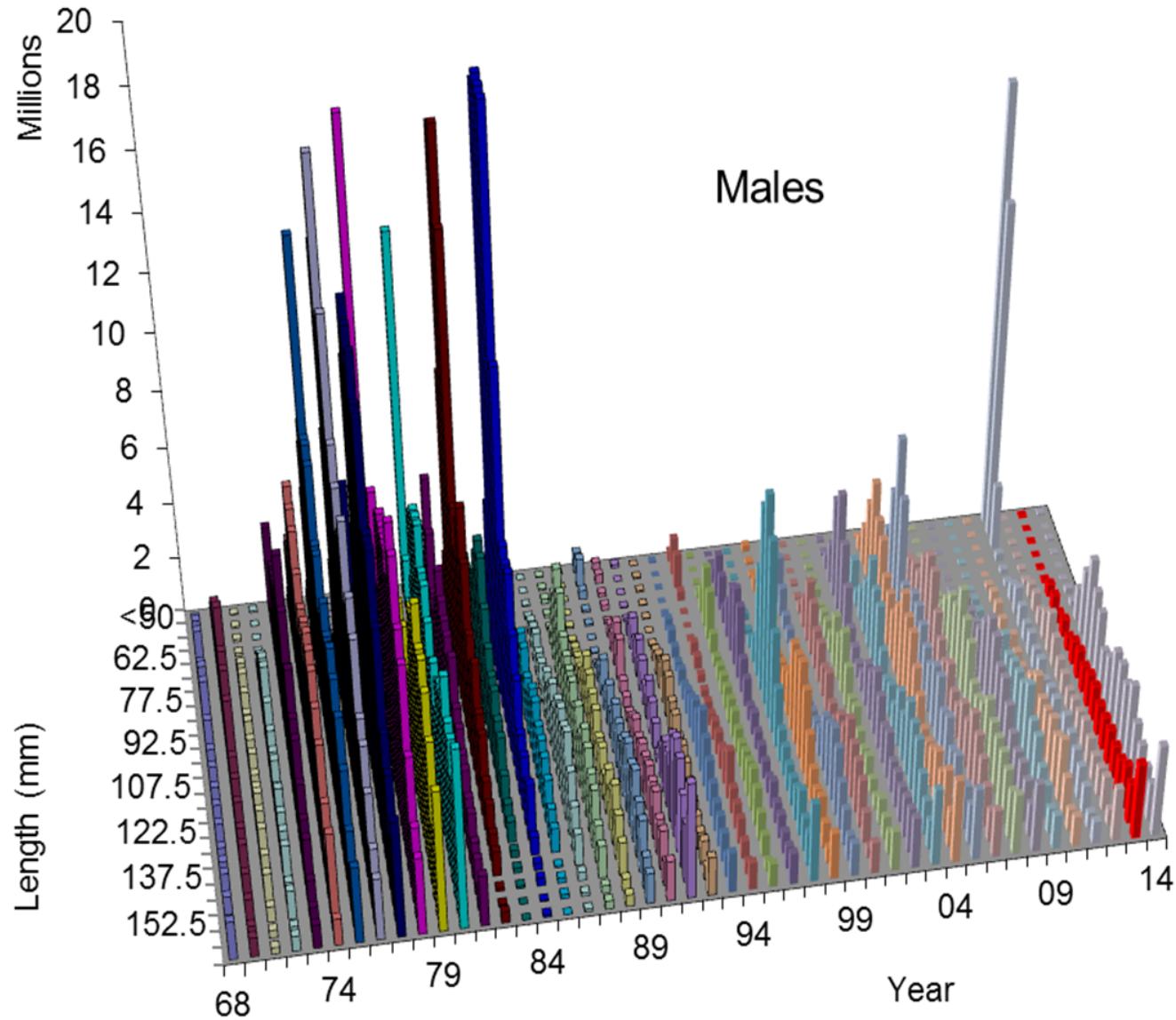
### Directed pot bycatch (1000 males)



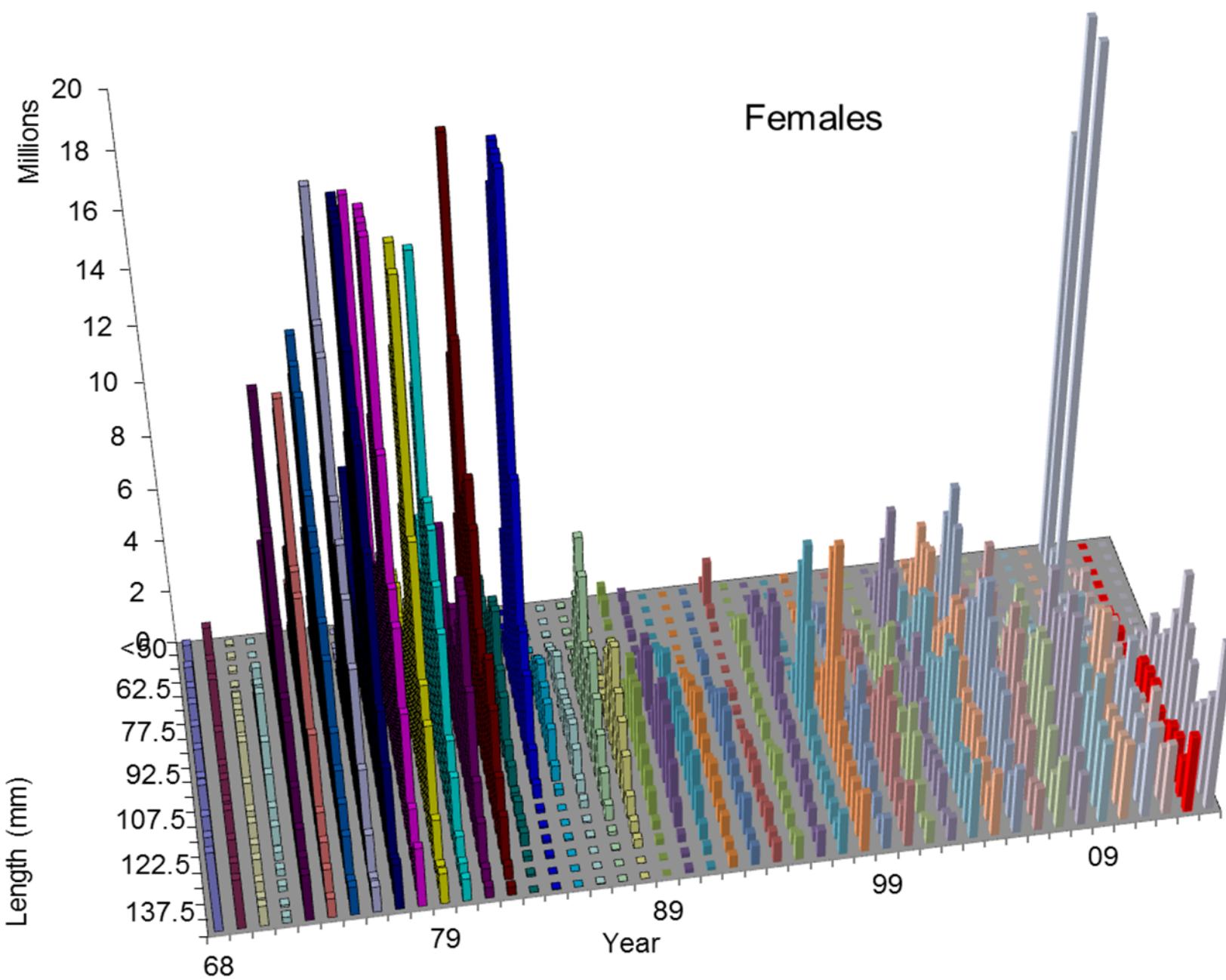
## Directed pot bycatch (1000 females)



## Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2014

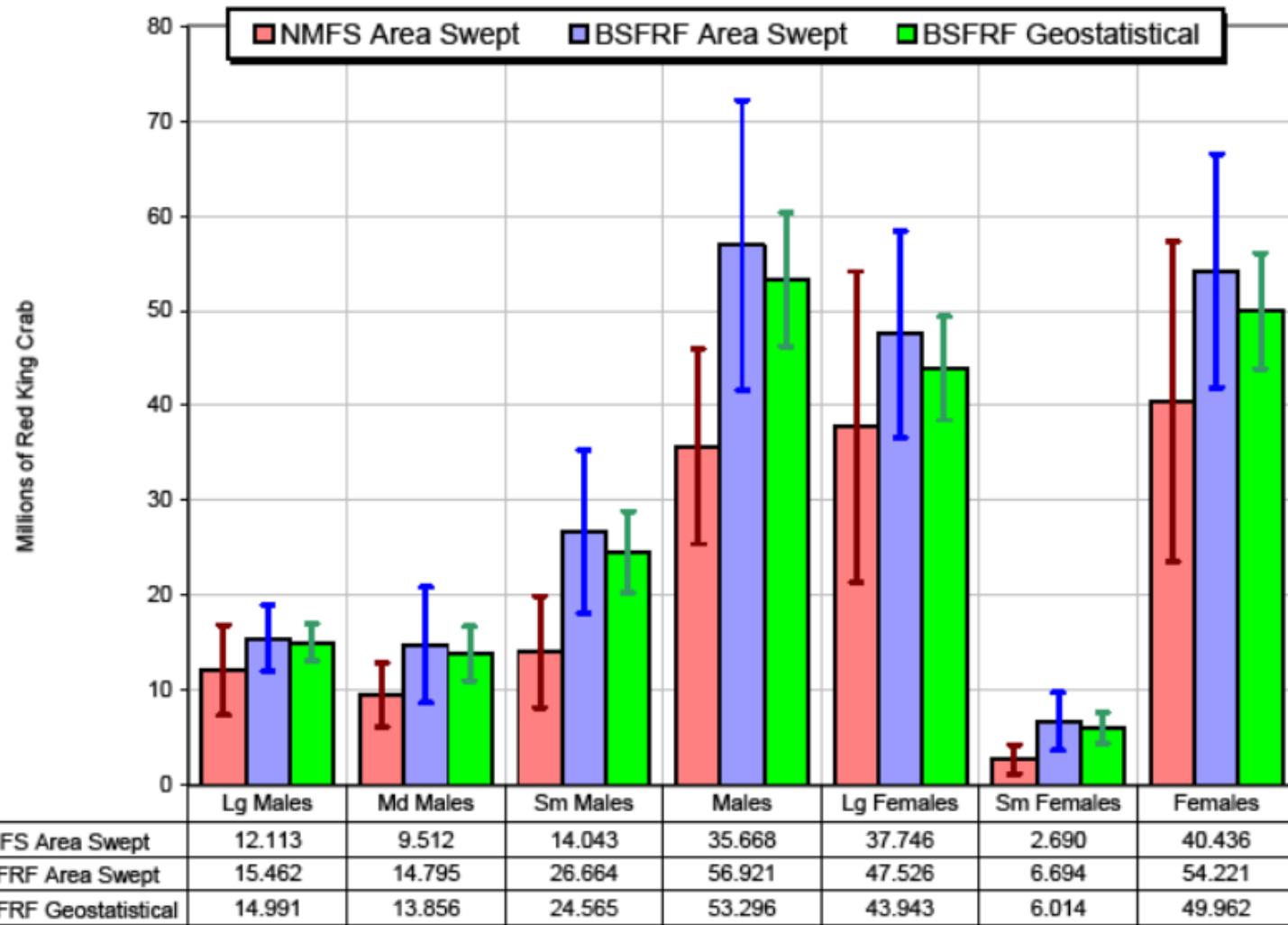


# Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2014

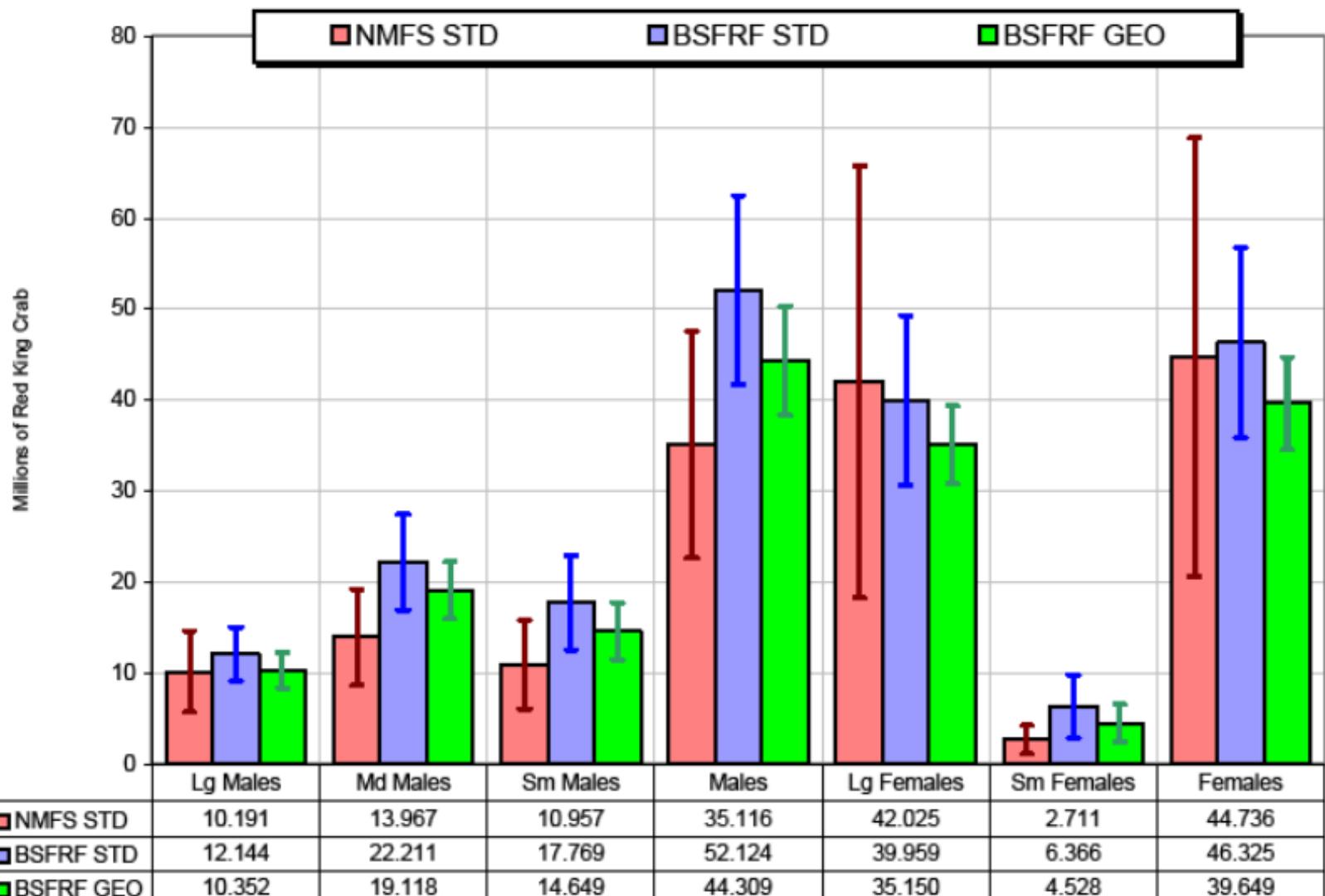


2007

# Comparison to NMFS



## 2008 SURVEY COMPARISON



# Assumptions of the model

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- The basic natural mortality (0.18) is constant over time, sex, shell conditions, and length and was estimated assuming a maximum age of 25 and the 1% rule.
- Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2014.
- Growth increments are a function of length and did not change over time for males. For females, three growth increments per molt as a function of length were estimated based on sizes at maturity (1975-1982, 1983-1993, and 1994-2014). Once mature, female red king crabs grow with a much small growth increment per molt.
- Variation of growth increments per molt and recruitment length distribution are a gamma function.
- Molting probabilities are an inverse logistic function of length for males.
- Annual fishing seasons for the directed fishery are short (instant catch).
- NMFS survey catchability ( $Q$ ) was estimated inside the model based on a trawl experiment by Weinberg et al. (2004) and the BSFRF surveys (catchability for BSFRF surveys is assumed to be 1).  $Q$  was assumed to be constant over time.
- Males mature at sizes  $\geq 120$  mm CL. For convenience, female abundance was summarized at sizes  $\geq 90$  mm CL as an index of mature females.
- Handling mortality: pot fishery = 0.2, Tanner crab fishery = 0.25, trawl fishery = 0.8
- High grading parameters ( $hg$ ) for 2005-2013 are estimated from observer data.

## Population dynamic:

$$N_{l,t+1}^s = \sum_{l'=1}^l \{ P_{l',l,t}^s [(N_{l',t}^s + O_{l',t}^s) e^{-M_t^s} - (C_{l',t}^s + D_{l',t}^s) e^{(y_t-1)M_t^s} - T_{l',t}^s e^{(j_t-1)M_t^s}] m_{l',t}^s \} + R_{t+1}^s U_l^s$$

$$O_{l,t+1}^s = [(N_{l,t}^s + O_{l,t}^s) e^{-M_t^s} - (C_{l,t}^s + D_{l,t}^s) e^{(y_t-1)M_t^s} - T_{l,t}^s e^{(j_t-1)M_t^s}] (1 - m_{l,t}^s)$$

where

$N$  and  $O$ : New and oldshell crab abundance,

$s, l, t$ : Sex, length class, and year,

$P$ : Growth matrix,

$M$ : Instantaneous natural mortality,

$m$ : Molting probability

$R$ : Annual recruitment,

$U$ : Length-class proportions of recruits,

$y, j$ : Lags in years between assessment survey and the mid directed fishery

time and between the assessment survey and the mid Tanner crab fishery time,

$C$ : Retained catch,

$D$ : Discarded mortality catch from directed pot and trawl fisheries, and

$T$ : Discarded mortality catch from the Tanner crab fishery.

Growth matrix:

$$P_{l,l',t}^s = \int_{L_l - \Delta L/2}^{L_l + \Delta L/2} \frac{x^{\alpha_{L_l,t}^s} e^{x/\beta^s}}{(\beta^s)^{\alpha_{L_l,t}^s} \Gamma(\alpha_{L_l,t}^s)} dx$$
$$\alpha_{L_l,t}^s \beta^s = a_t^s + b_t^s L_l$$

Retained catch or bycatch from directed pot and trawl fisheries:

$$G_{l,t}^s = (N_{l,t}^s + O_{l,t}^s) e^{-y_t M_t^s} (1 - e^{-F_{l,t}^s})$$

Bycatch from the Tanner crab fishery:

$$T_{l,t}^s = (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} e^{-F_{l,t}^s} (1 - e^{-F_{l,t}^s})$$

## Trawl survey and fisheries selectivities other than directed pot male selectivity:

$$S_l^{type} = \frac{1}{1 + e^{-\beta^{type} (\iota - L_{50}^{type})}}$$

Where

$\beta^{type}$  and  $L_{50}^{type}$  are parameters.

## Directed pot male bycatch selectivity:

$$S_l = \varphi + \kappa \iota, \quad \text{if } \iota < 135 \text{ mm CL},$$

$$S_l = S_{l-1} + 5\gamma, \quad \text{if } \iota > 134 \text{ mm CL}$$

Where

$\varphi, \kappa, \gamma$  are parameters.

# Mortalities

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- Directed pot fishing
- Indirected pot fishing (Tanner crab fishery)
- Bottom trawling
- Basic natural mortality (0.18)
- Additional mortality (estimated in the model):
  - One parameter for males and one for females during 1980-1984
  - One parameter for females during both 1976-1979 and 1985-1993

# Bycatch mortalities before observer data

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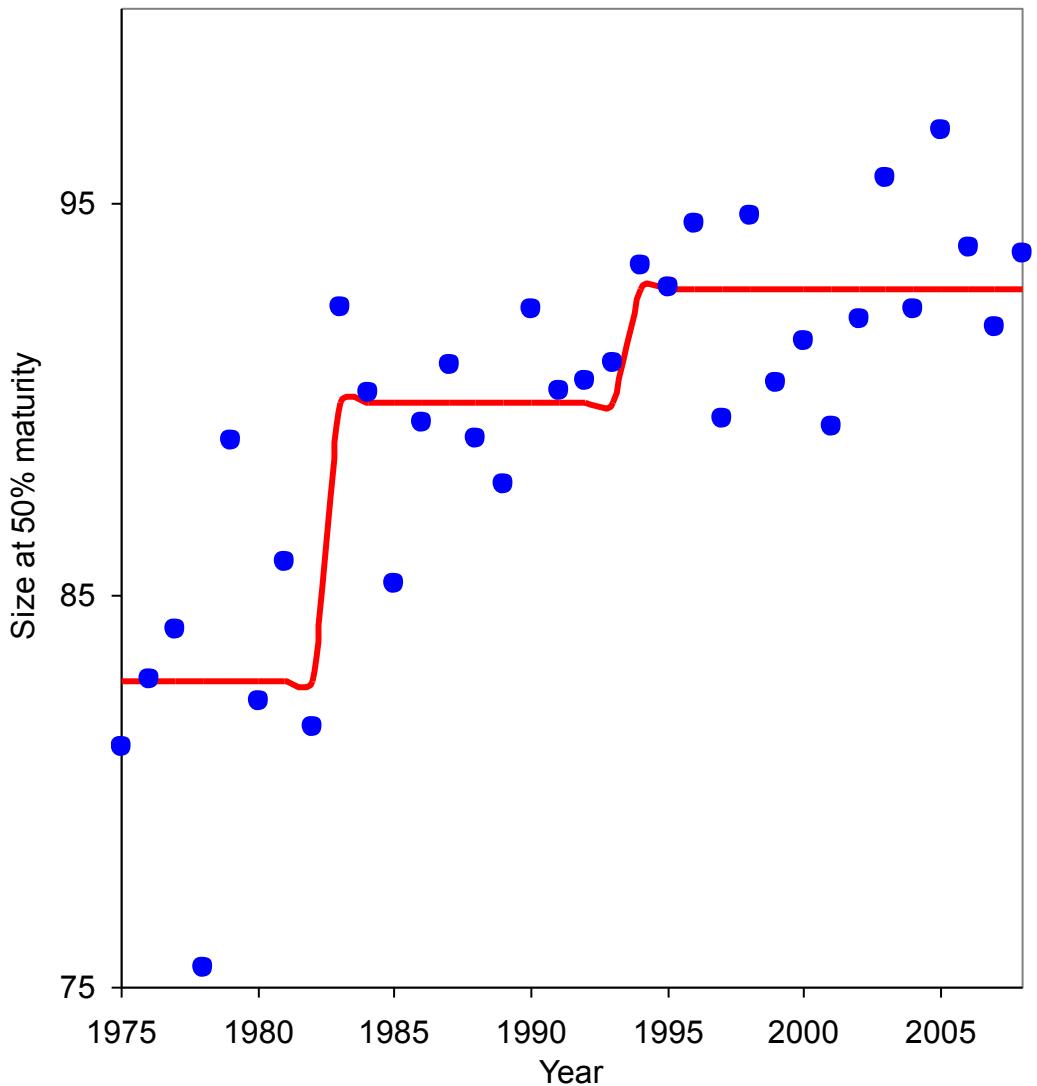
- Directed pot fishing (before 1990):
  - Full pot fishing mortality times median ratio of bycatch mortality over full pot fishing mortality during 1990-2004.
- Indirected pot fishing (Tanner crab fishery, before 1991):
  - Proportional to the smoothing average of Tanner crab fishery potlifts east of 163° W.
  - The smoothing average is equal to  $(P_{t-2}+2P_{t-1}+3P_t)/6$  for the potlifts in year t.
  - Bycatch mortality equal to total potlift times average ratio of bycatch mortality over total potlift during 1991-1993.

# Growth, Maturity and Spawning

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- Growth
  - Mainly from tagging data
  - Modal analysis
- Maturity
  - Survey data
  - Lab experiment
  - Field observation
- Spawning
  - Survey data

# Size at 50% Maturity for Females

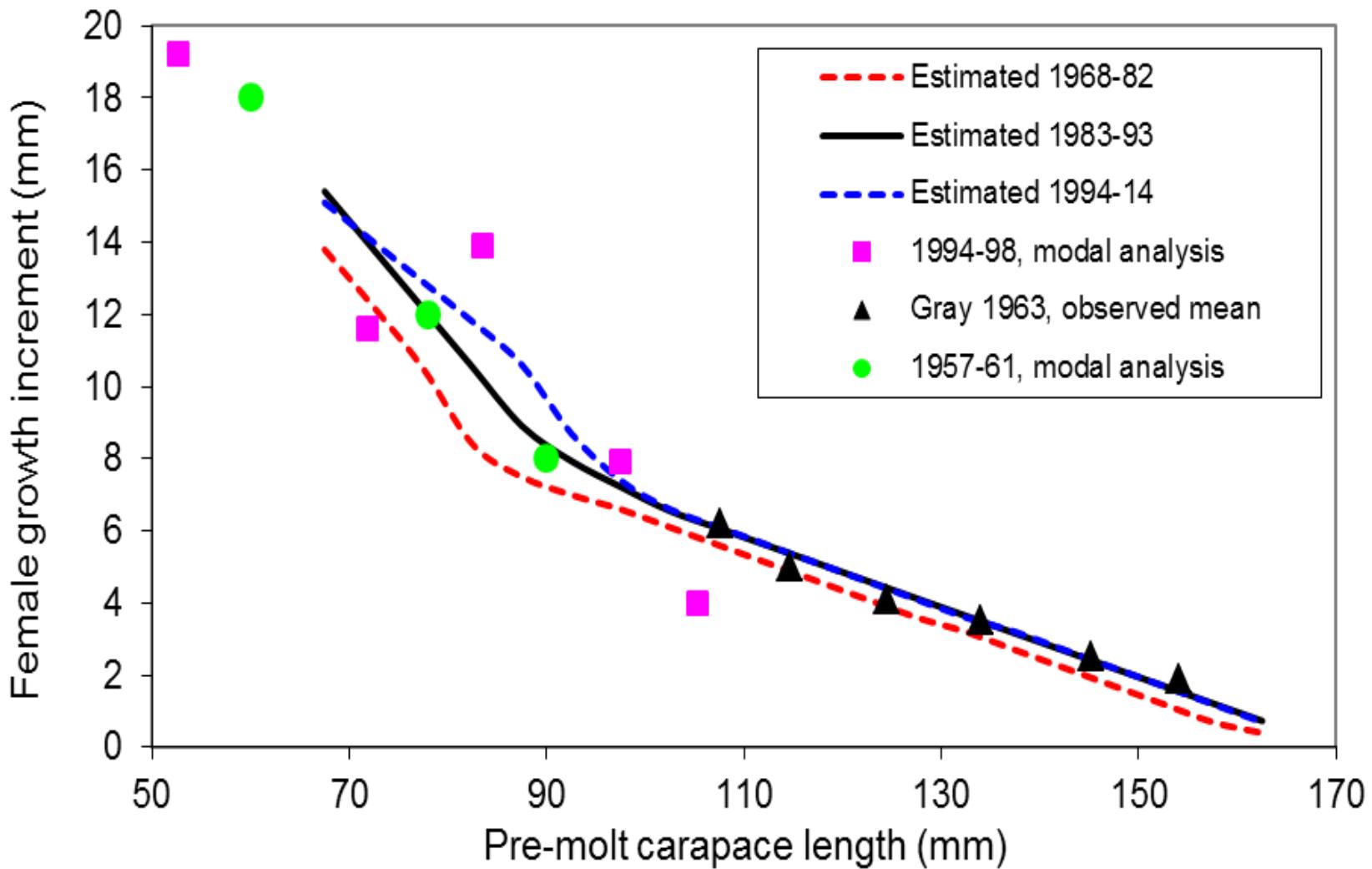


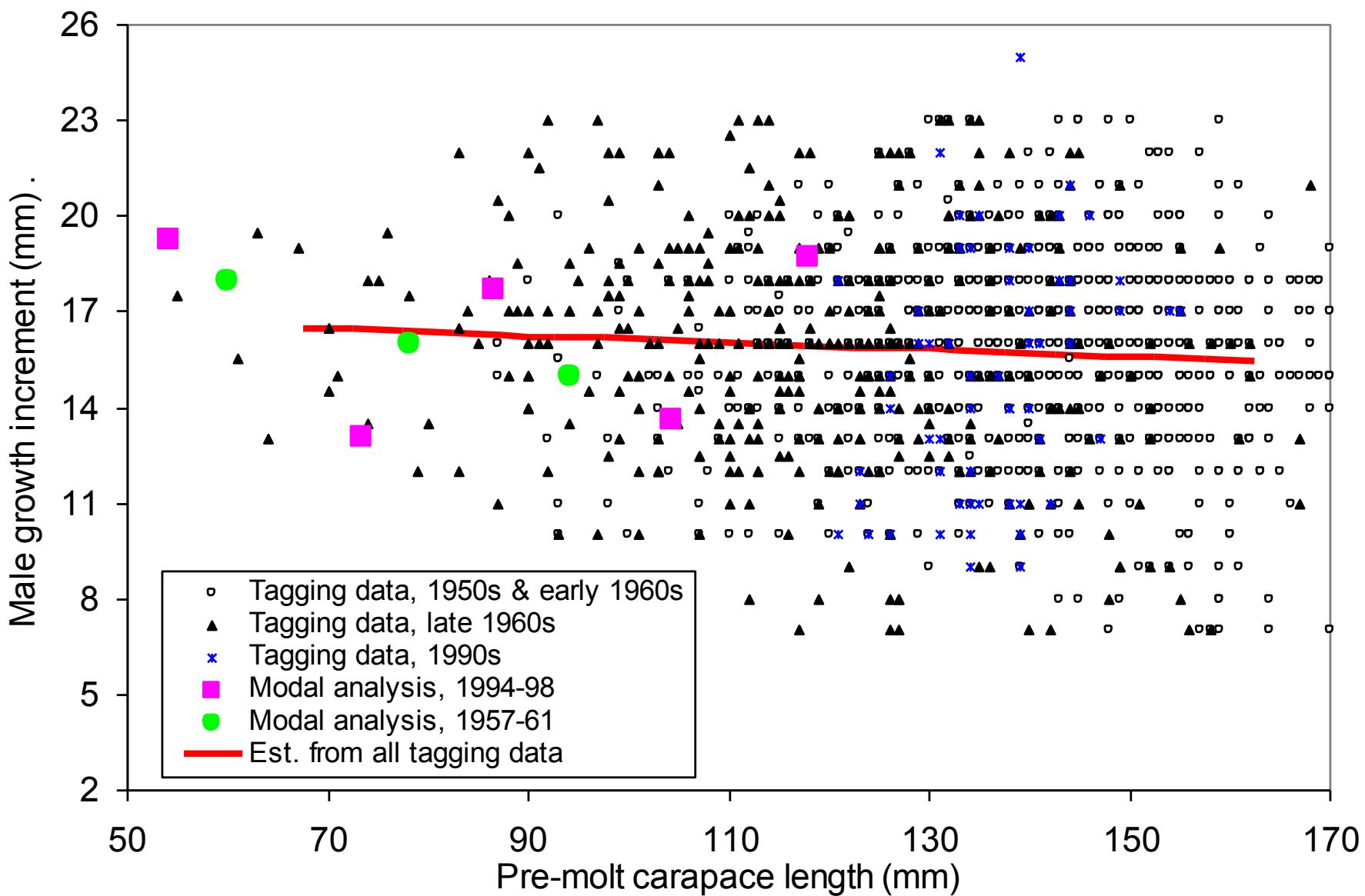
Estimated from the survey data with a logistic function.

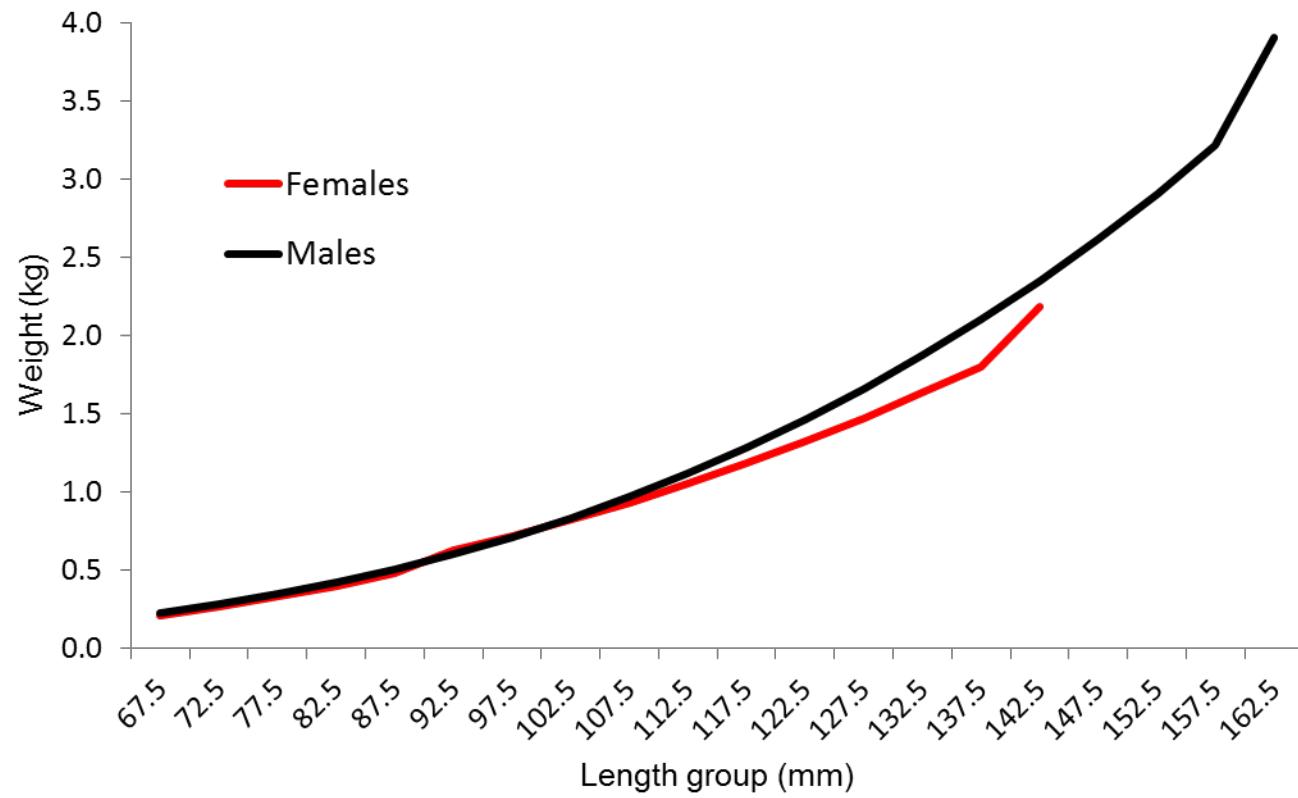
Three levels are assumed:  
1968-1982, 1983-1993,  
1994-2014

These are mainly used for determining growth of females

## Growth of females is maturity-dependent







# Likelihood functions

For length/shell composition:

$$Rf = \prod_{l=1}^L \prod_{t=1}^T \prod_{s=1}^2 \prod_{sh=1}^2 \frac{\left\{ \exp \left[ - \frac{(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh})^2}{2\sigma^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma^2}},$$

$$\sigma^2 = [\hat{p}_{l,t,s,sh}(1 - \hat{p}_{l,t,s,sh}) + 0.1/L]/n,$$

$L$  is the number of length groups,  
 $T$  is the number of years,  
 $n$  is the effective sample size.

The weighted negative log-likelihood functions are:

*Length compositions* :  $-\sum \ln(Rf_i)$ ,

*Biomasses other than survey* :  $\lambda_j \sum [\ln(C_t / \hat{C}_t)^2]$ ,

*NMFS survey biomass* :  $\sum [\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))]$ ,

*BSFRF mature males* :  $\sum [\ln(\ln(CV_t^2 + 1))^2 + \ln(N_t / \hat{N}_t)^2 / (2\ln(CV_t^2 + 1))]$ ,

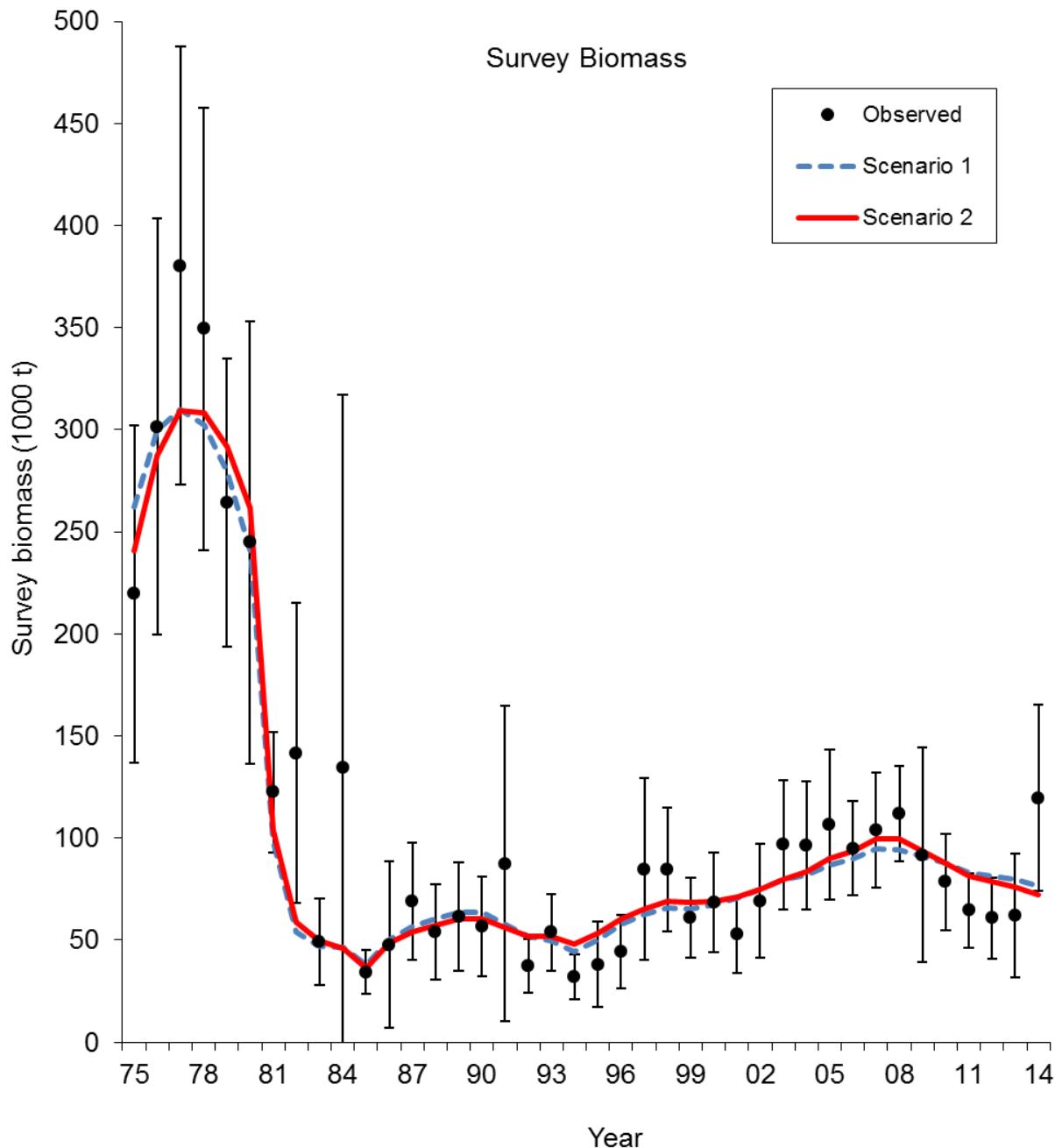
*NMFS survey  $Q$*  :  $(Q - Q_{\text{exp}})^2 / (2\sigma_{\text{exp}}^2)$ ,

*R variation* :  $\lambda_R \sum [\ln(R_t / \bar{R})^2]$ ,

*R sex ratio* :  $\lambda_s [\ln(\bar{R}_M / \bar{R}_F)^2]$ ,

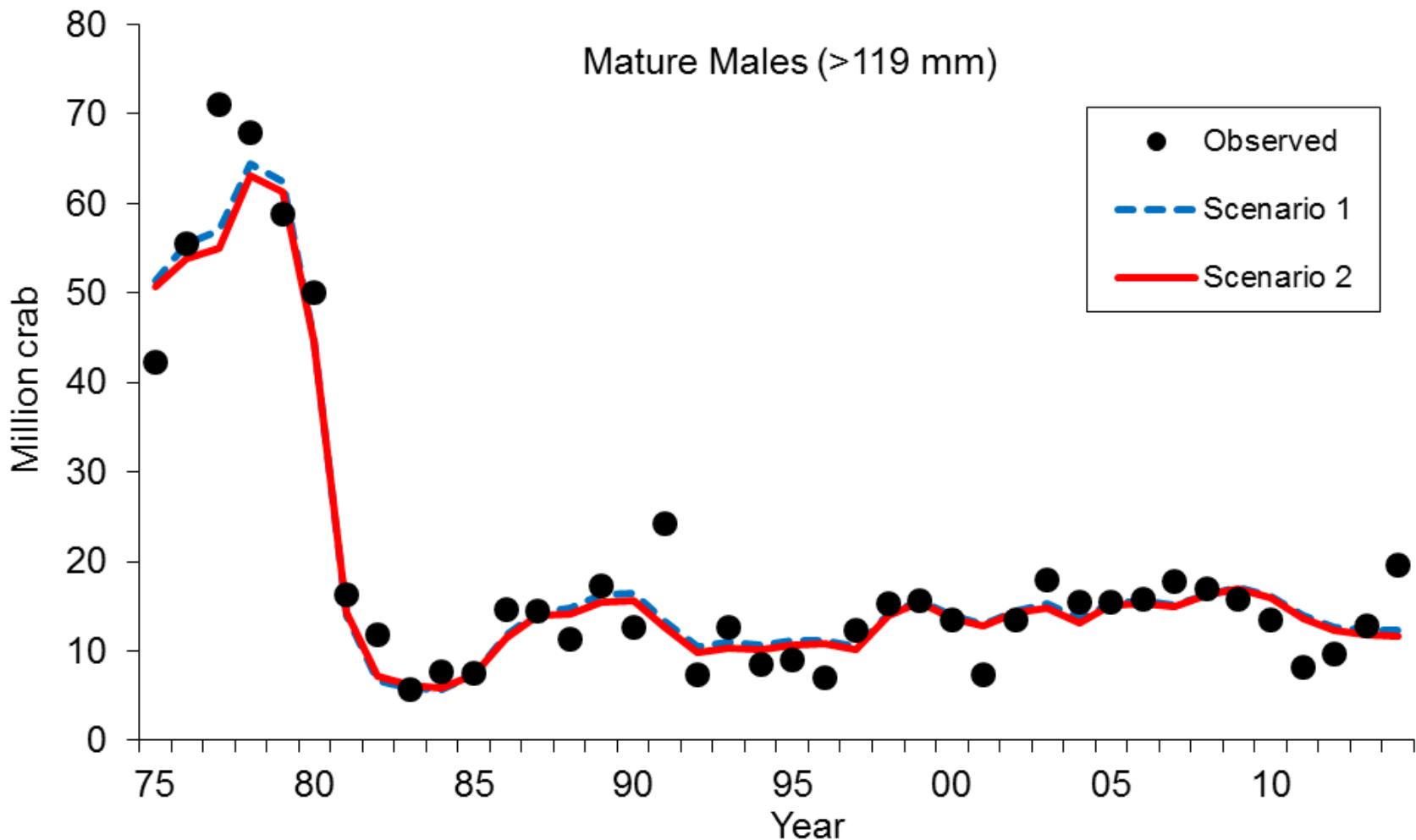
*Trawl bycatch fishing mortalities* :  $\lambda_t [\ln(F_{t,t} / \bar{F}_t)^2]$ ,

*Pot female bycatch fishing mortalities* :  $\lambda_p [\ln(F_{t,f} / \bar{F}_f)^2]$ .

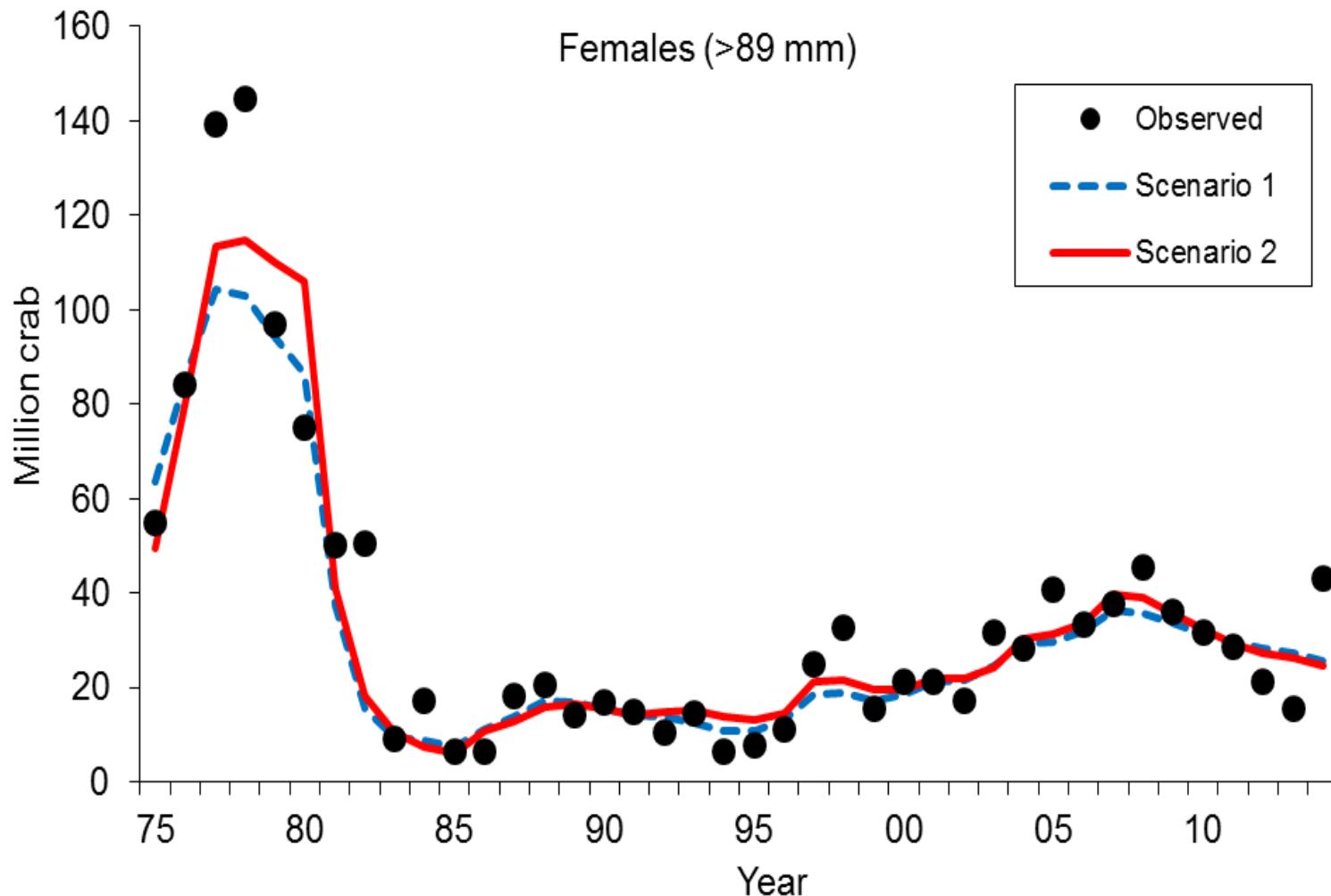


The observed values in this figure are from the current time series used in 2014.

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The observed values in this figure are from the current time series used in 2014.



## Comparisons of total survey biomass estimates by the BSFRF survey and the model

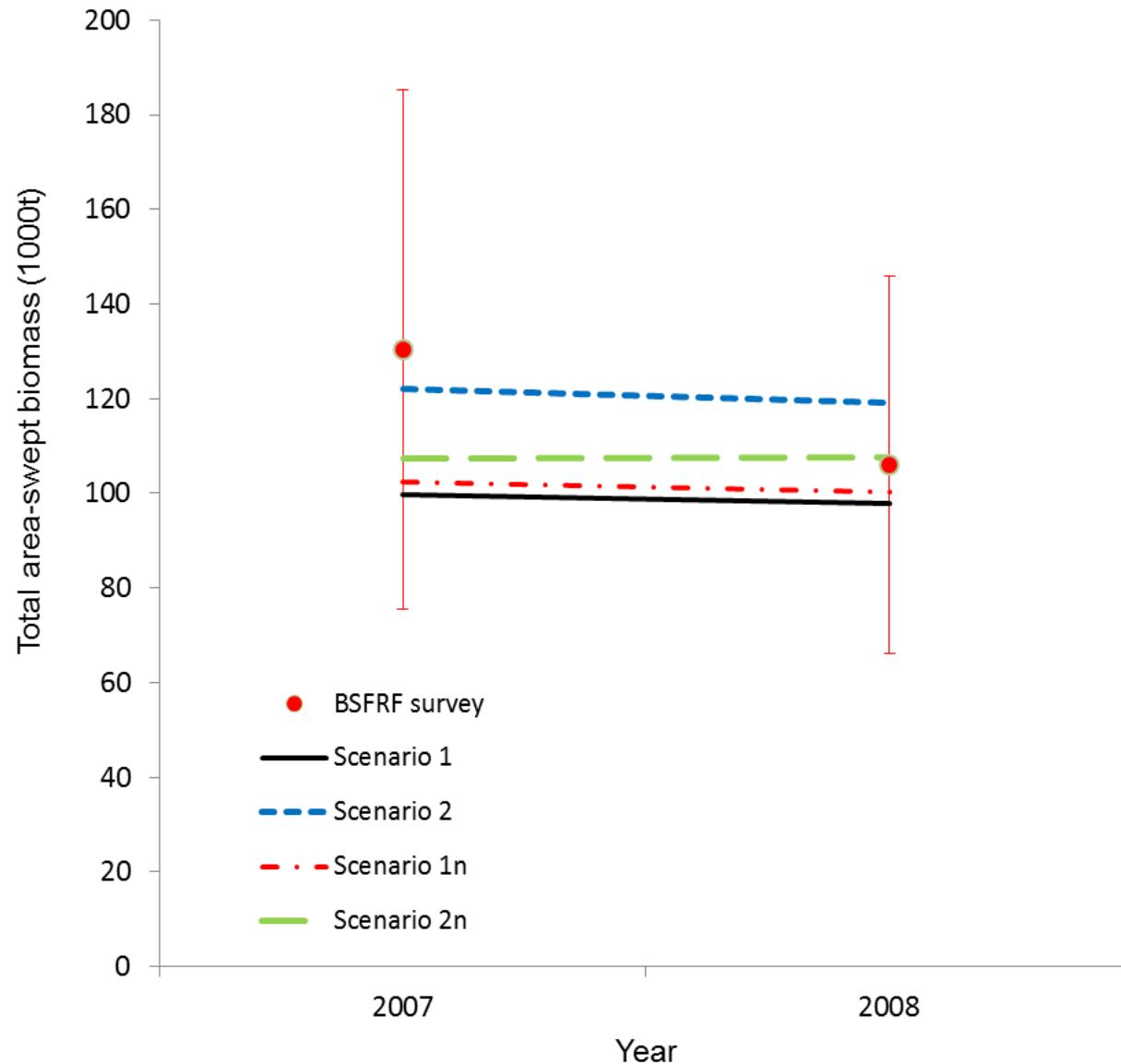
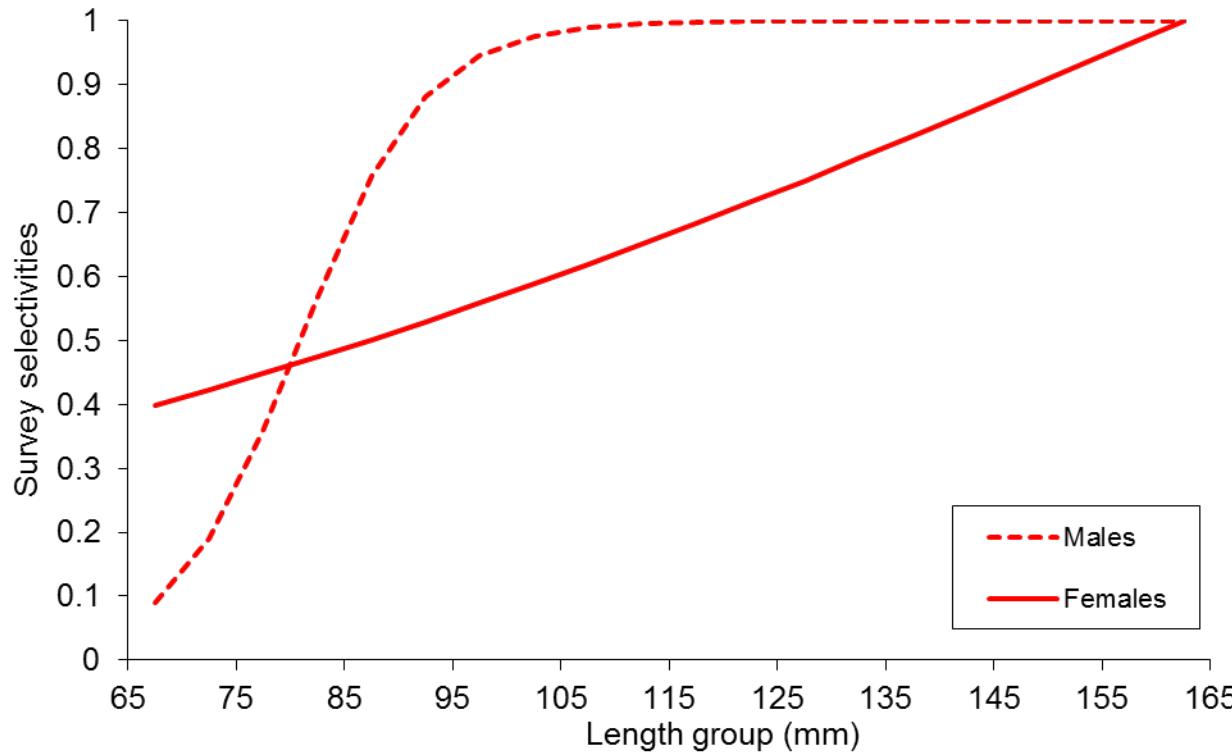
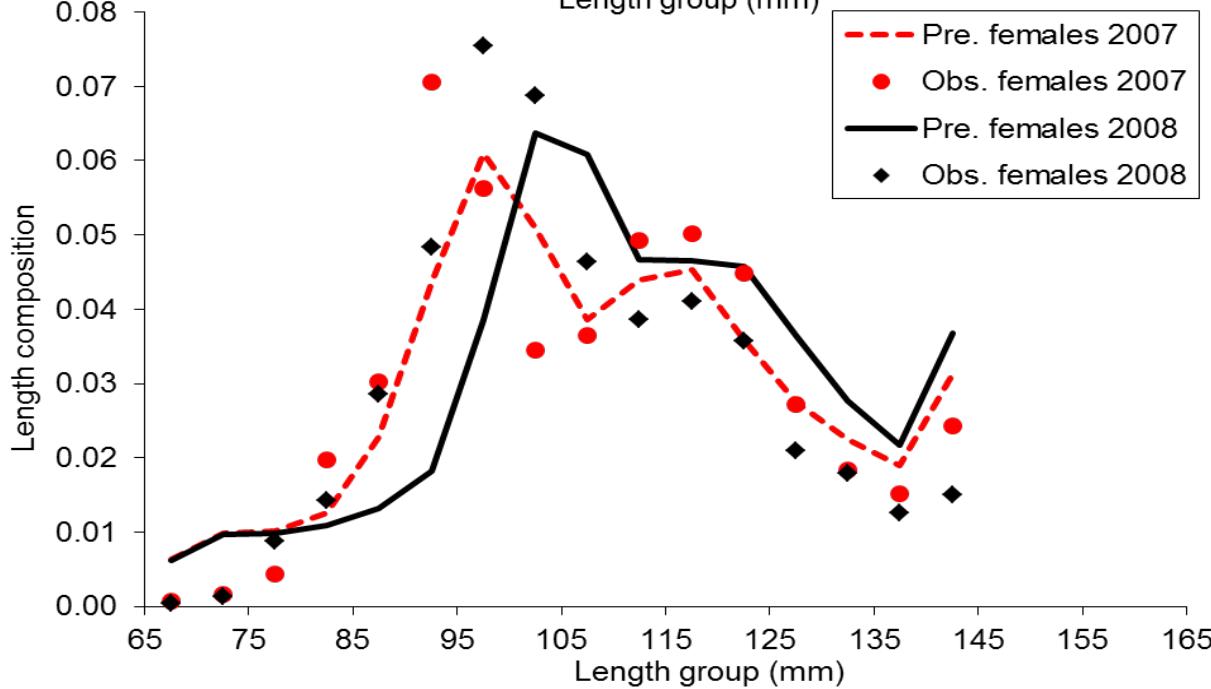
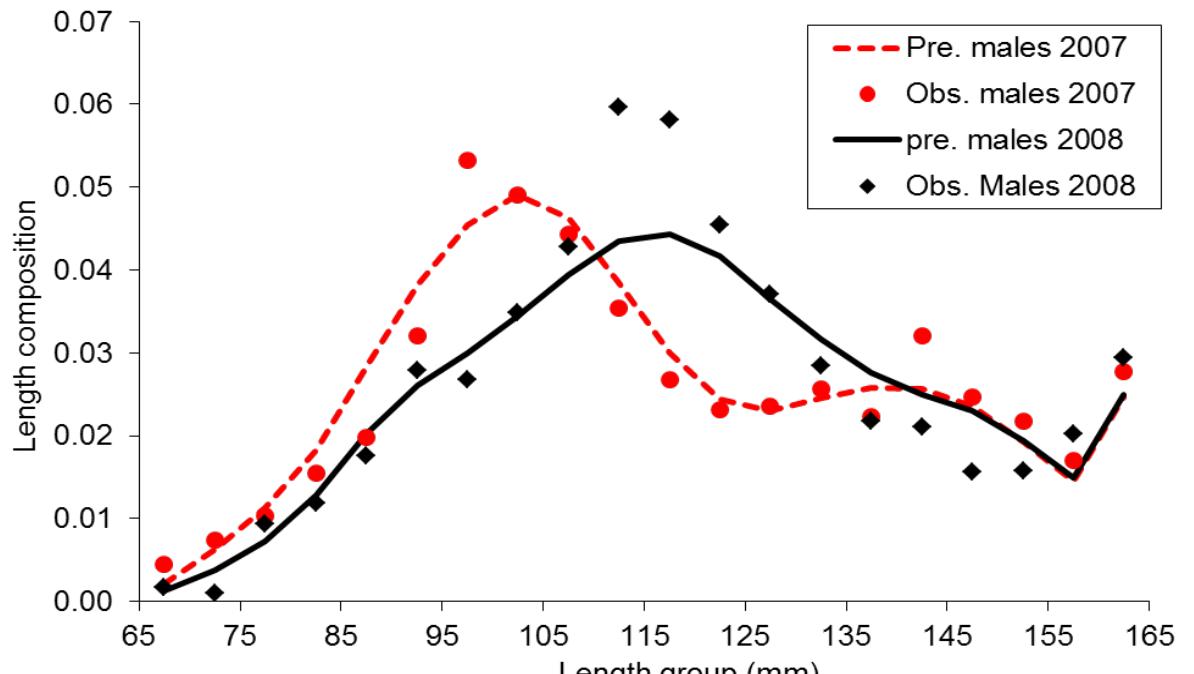


Table 4. Negative log likelihood components for scenarios 1 and 1n and differences in negative log-likelihood components among model scenarios.

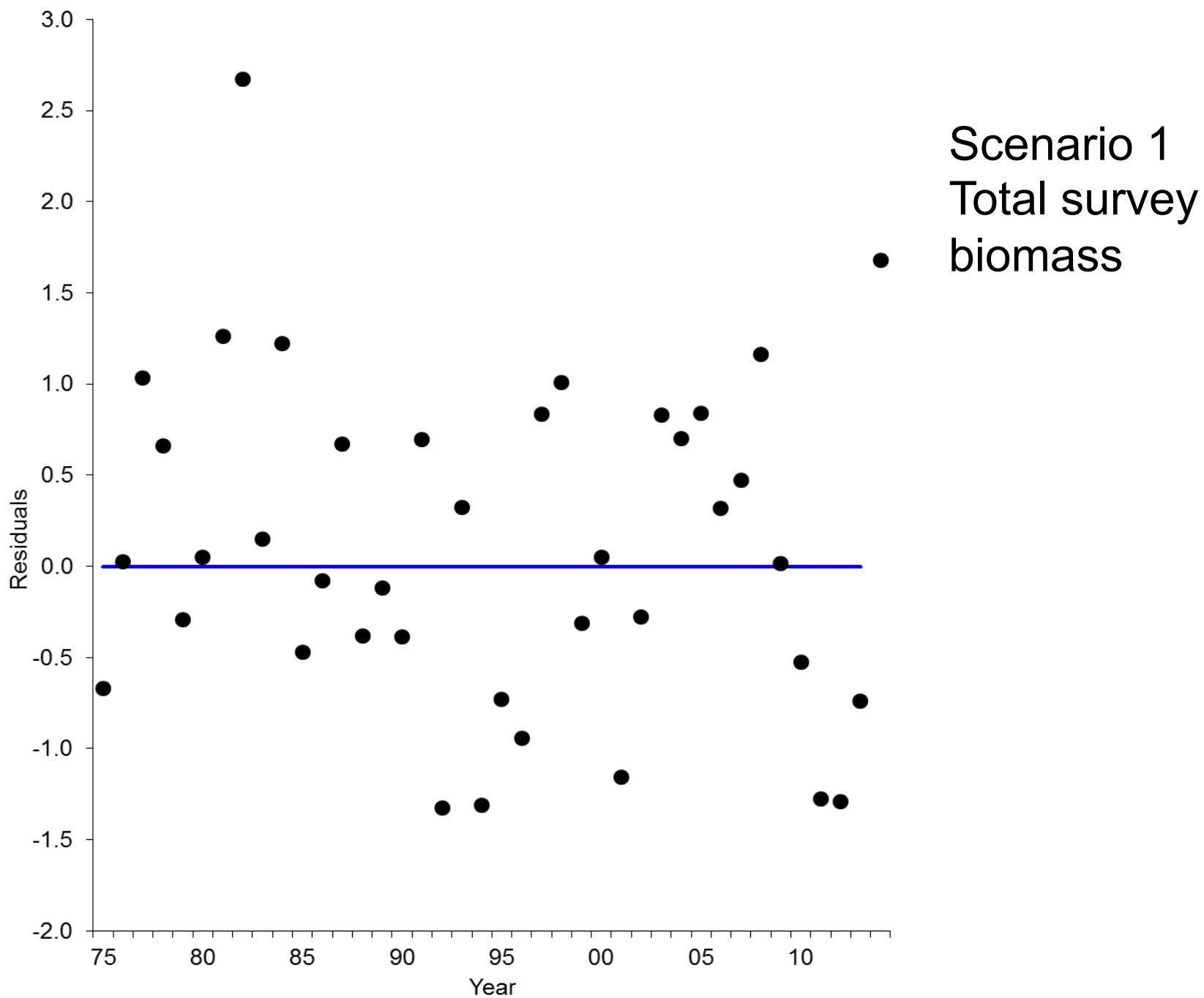
	Scenario						
	1	1n	2	2n	1n - 1	2 - 1	2n - 1n
Negative log likelihood							
R-variation	78.01	80.86	94.30	95.00	2.84	16.28	14.15
Length-like-retained	-949.47	-951.44	-947.83	-951.93	-1.97	1.64	-0.49
Length-like-discmale	-953.27	-953.31	-958.20	-958.34	-0.04	-4.92	-5.03
Length-like-discfemale	-2251.11	-2254.15	-2261.53	-2266.52	-3.04	-10.42	-12.37
Length-like-survey	-44873.70	-44971.70	-45129.80	-45273.50	-98.00	-256.10	-301.80
Length-like-disctrawl	-1966.13	-1967.25	-1974.42	-1977.70	-1.12	-8.29	-10.45
Length-like-discTanner	-330.79	-330.65	-330.28	-332.63	0.14	0.51	-1.98
Length-like-bsfrfsurvey	-237.30	-237.99	-228.22	-232.02	-0.69	9.08	5.97
Catchbio_retained	46.63	46.73	48.17	48.20	0.09	1.53	1.47
Catchbio_discmale	210.27	216.59	212.05	216.65	6.32	1.78	0.06
Catchbio-discfemale	0.14	0.13	0.60	0.42	0.00	0.46	0.28
Catchbio-disctrawl	0.86	0.91	0.87	0.93	0.05	0.02	0.02
Biomass-trawl survey	85.37	92.91	85.91	93.25	7.54	0.55	0.34
Biomass-bsfrfsurvey	-5.42	-4.42	-3.42	-2.42	1.00	2.00	2.00
Others	23.62	21.19	134.20	98.11	-2.43	110.58	76.92
Total	-51122.30	-51211.60	-51257.60	-51442.50	-89.30	-135.30	-230.90
Free parameters	265	265	314	314	0	49	49

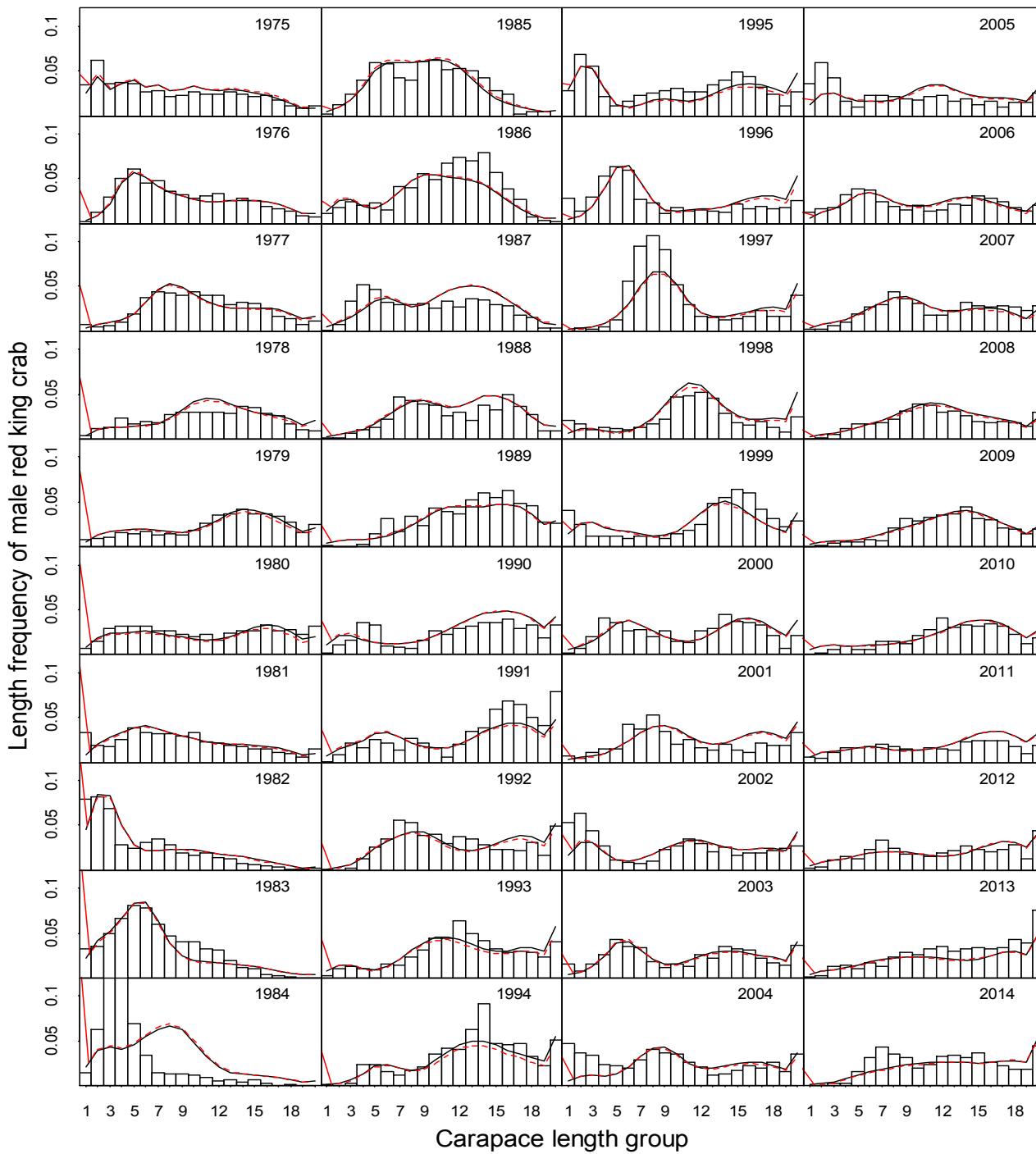


Estimated BSFRF survey selectivities with scenario 1. The catchability is assumed to be 1.0.

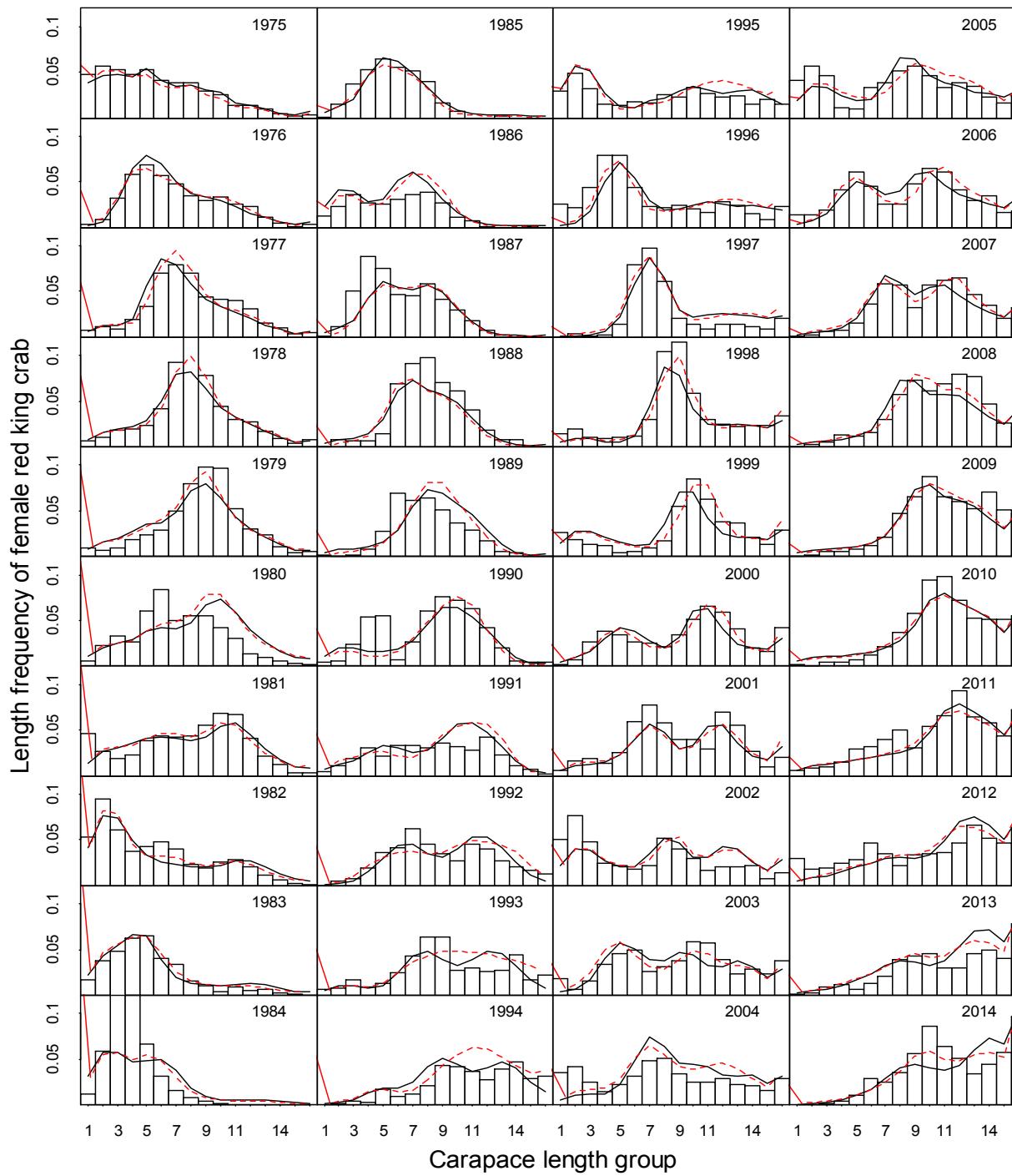


Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 1.

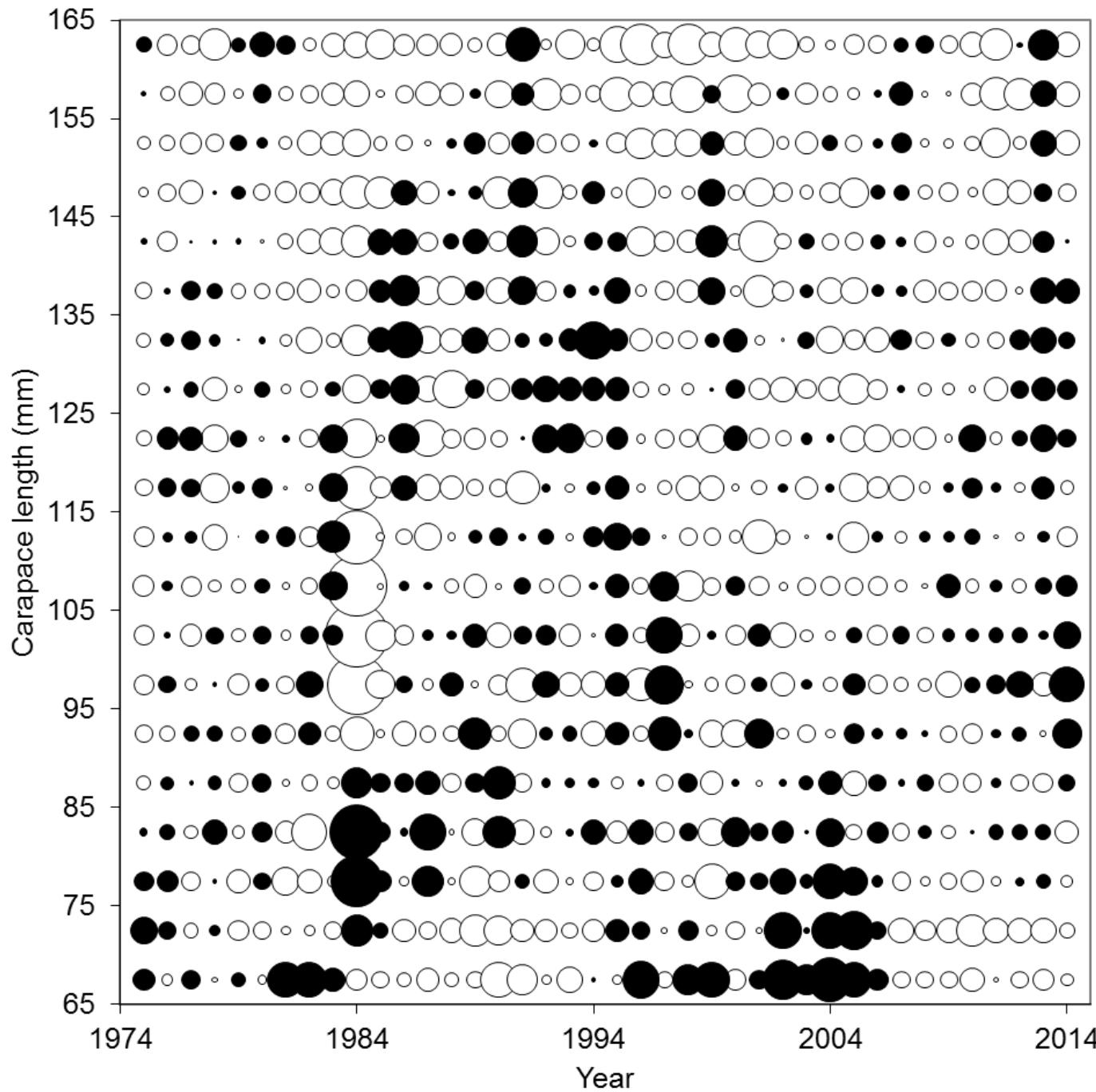




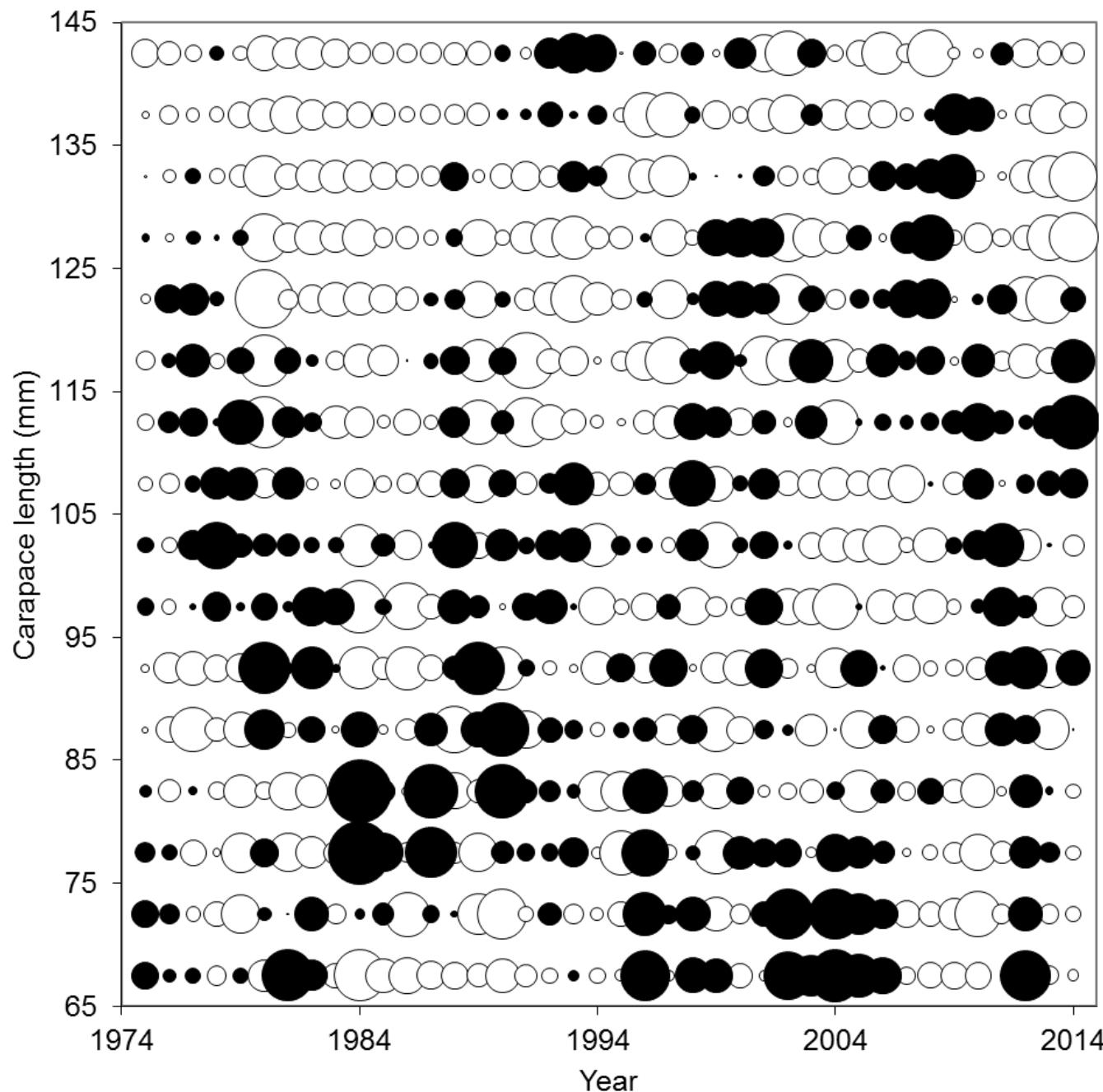
Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenarios 1(solid black) and 2(dashed red). The first length group is 67.5 mm.



Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenarios 1(solid black) and 2(dashed red). The first length group is 67.5 mm.

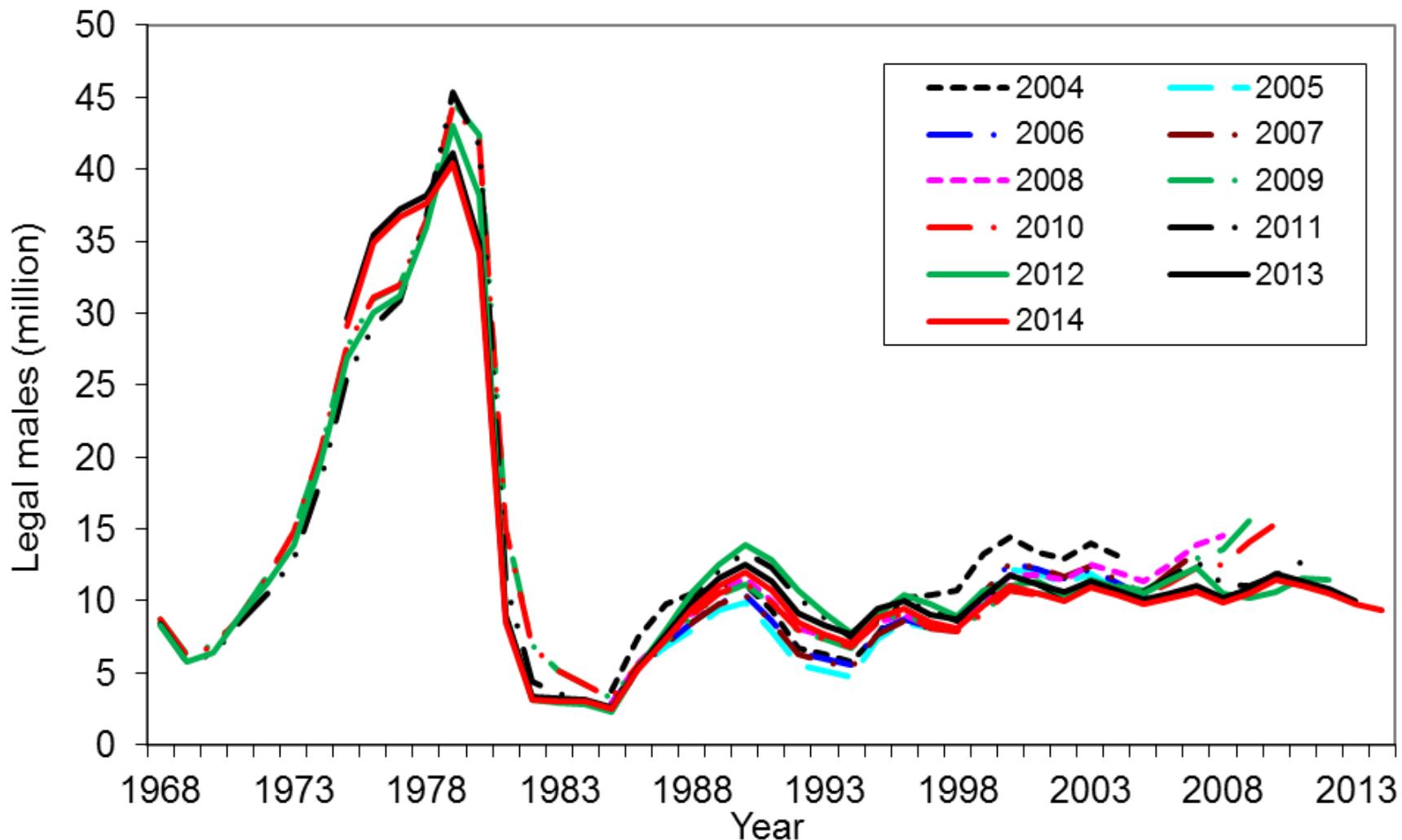


Scenario 1  
Males

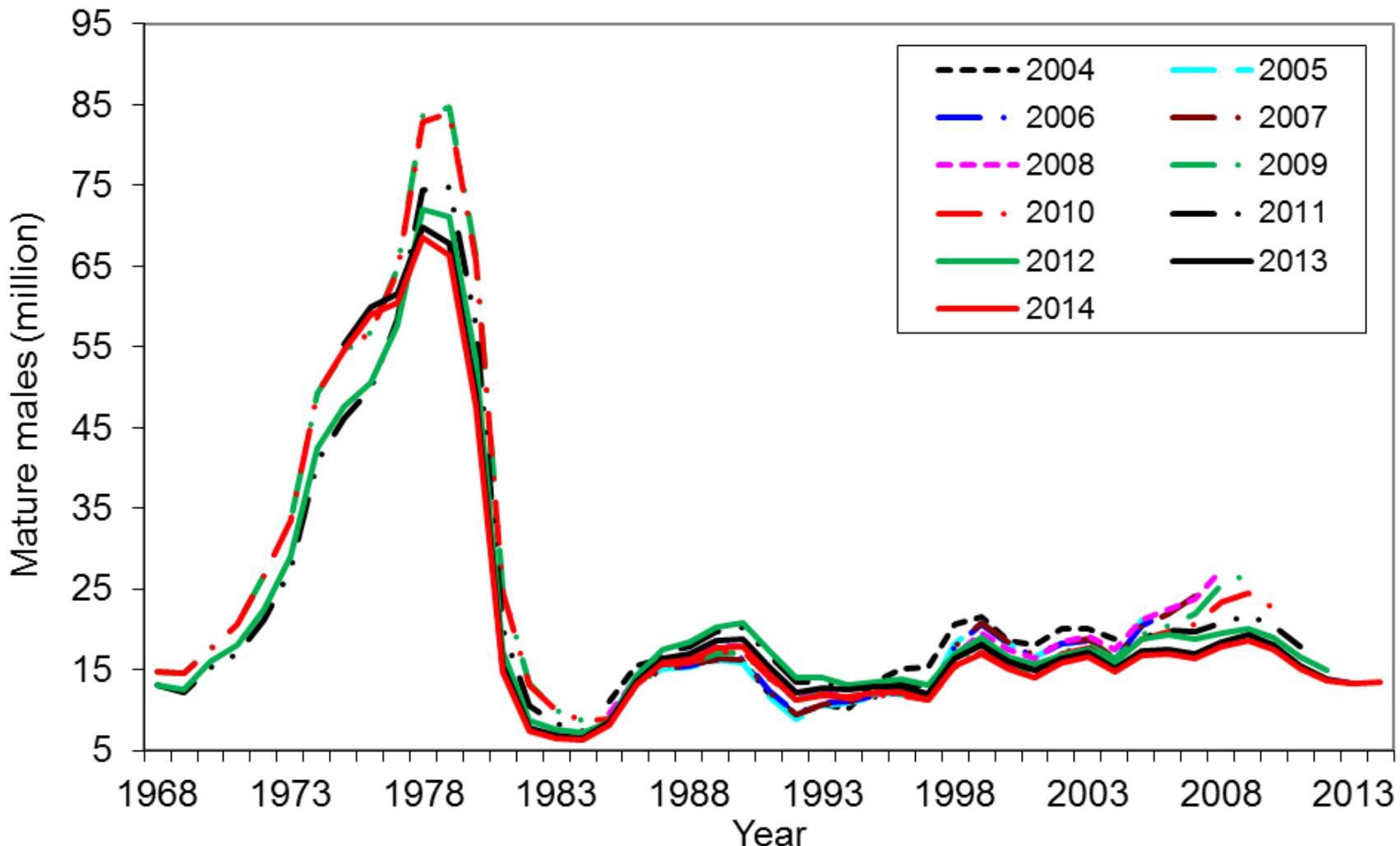


Scenario 1  
Females

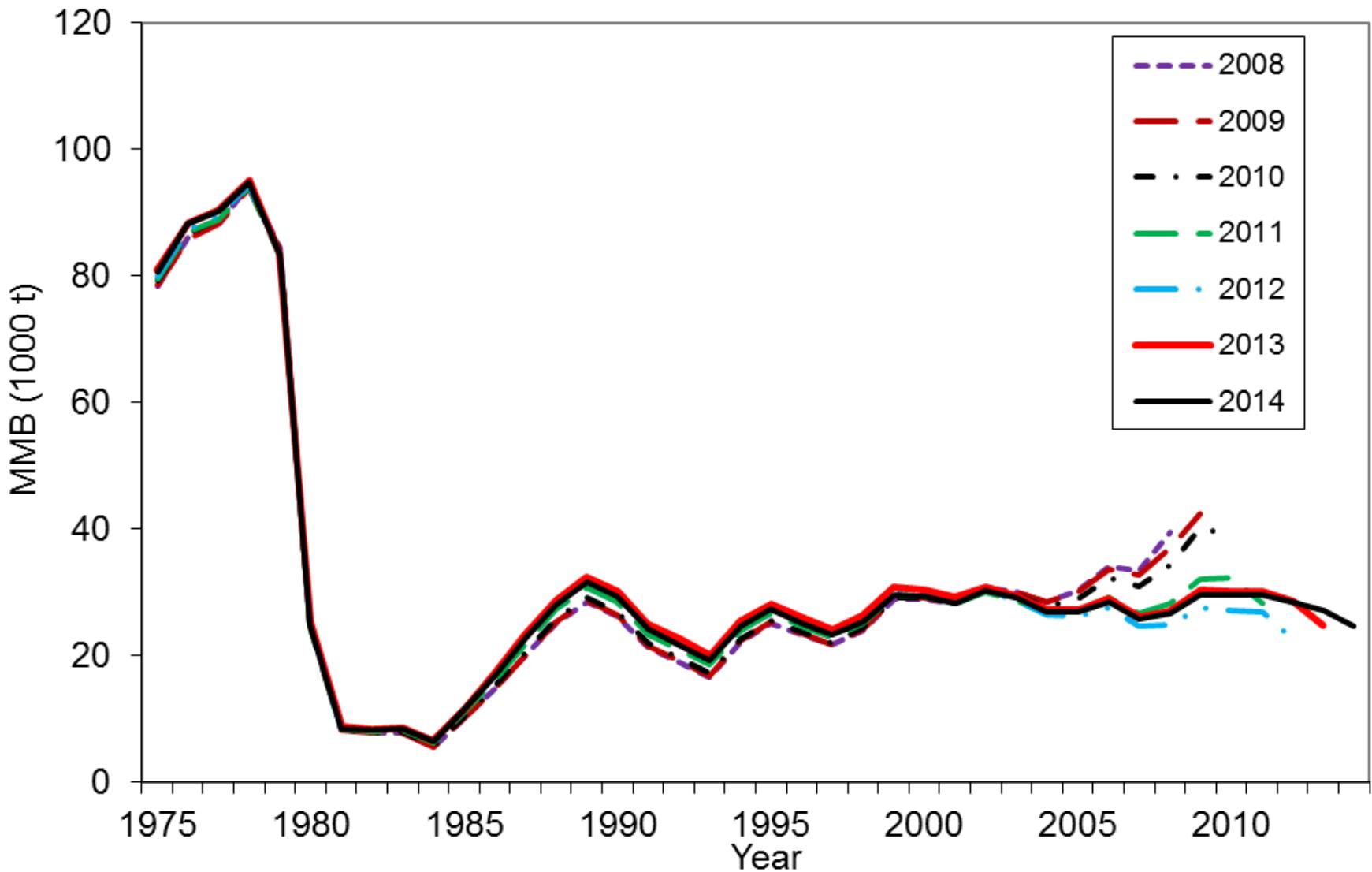
# Scenario 1 in 2014, historical results



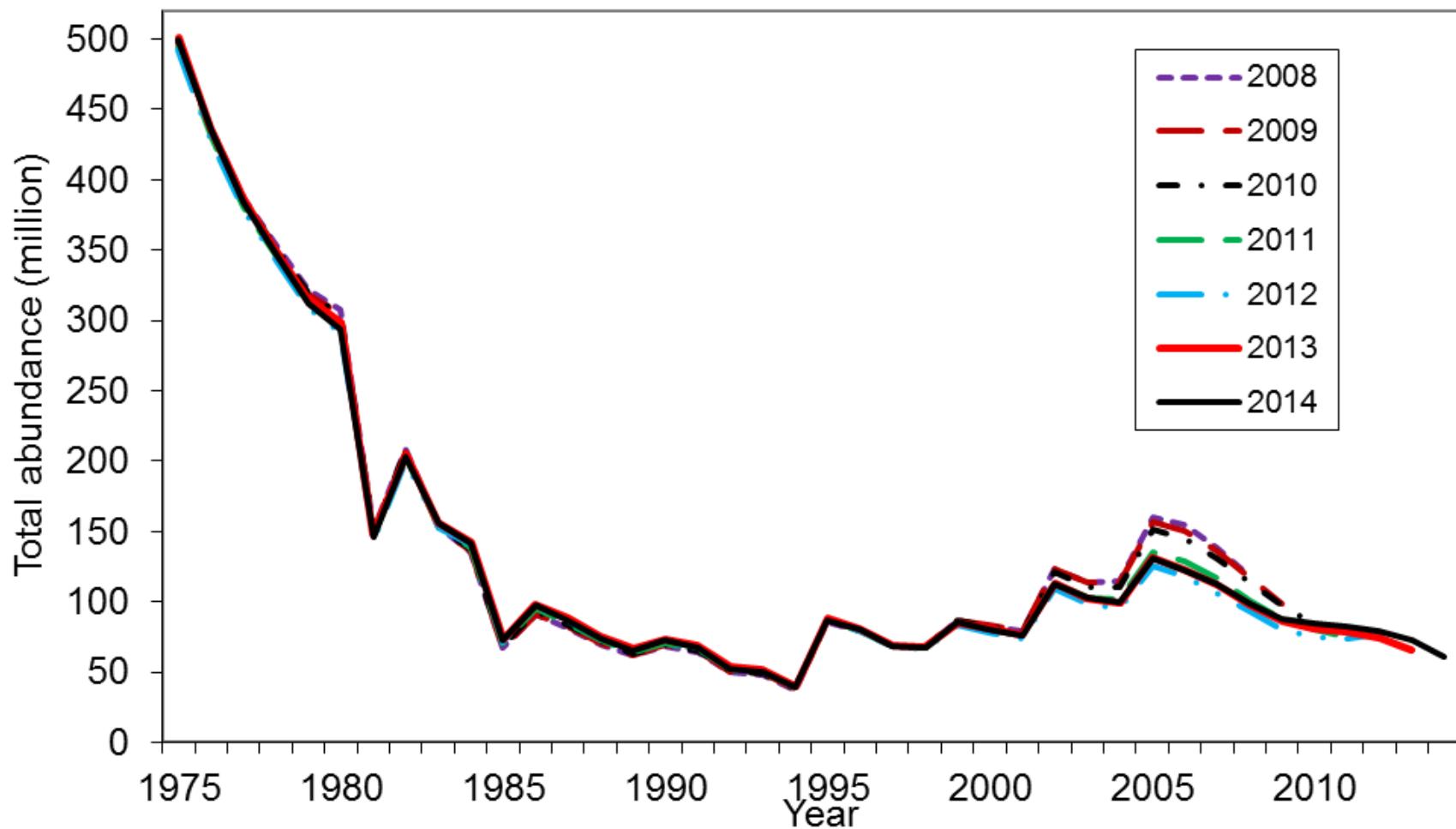
# Scenario 1 in 2014, historical results



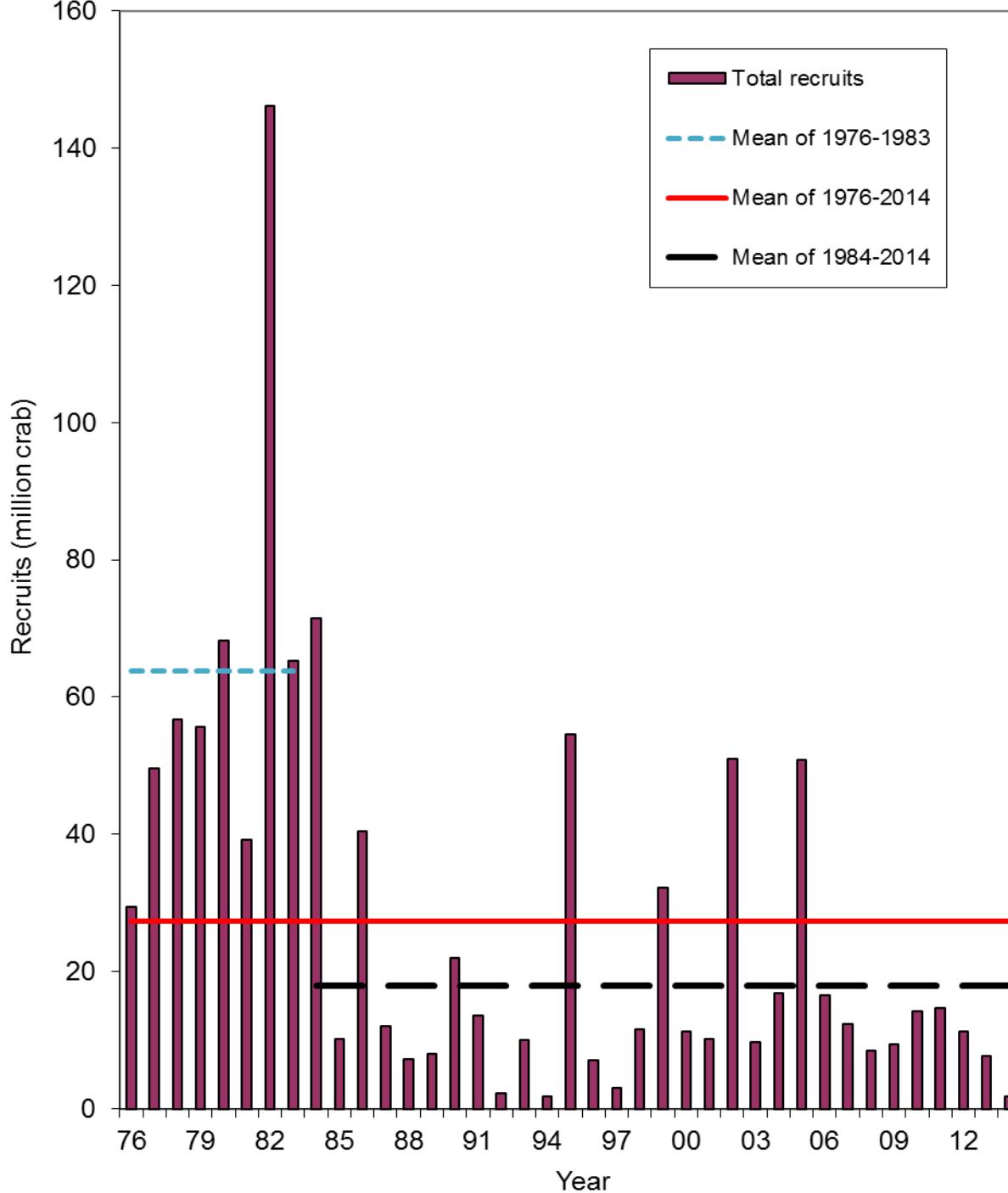
# Scenario 1, 2014 model results



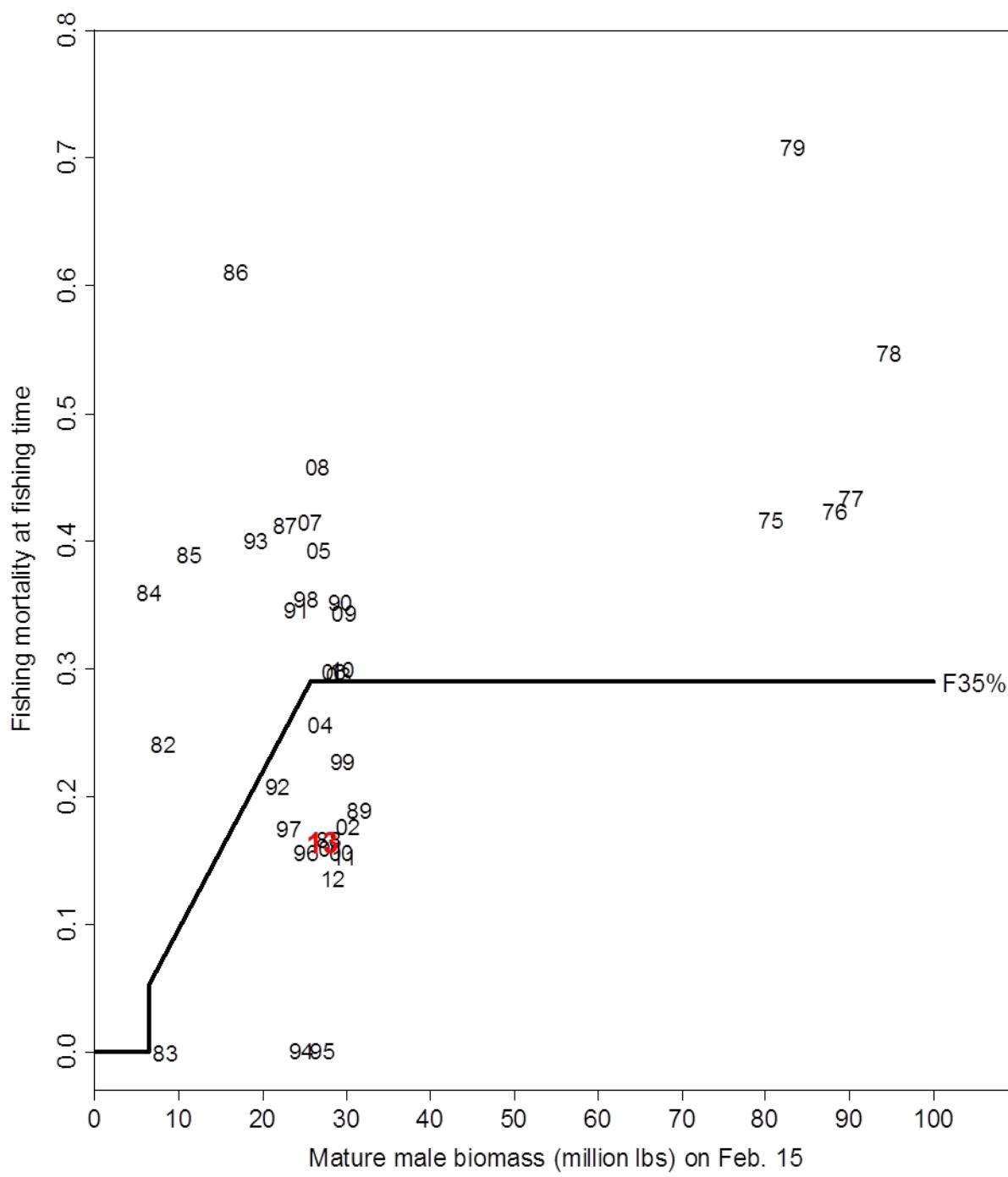
# Scenario 1, 2014 model results



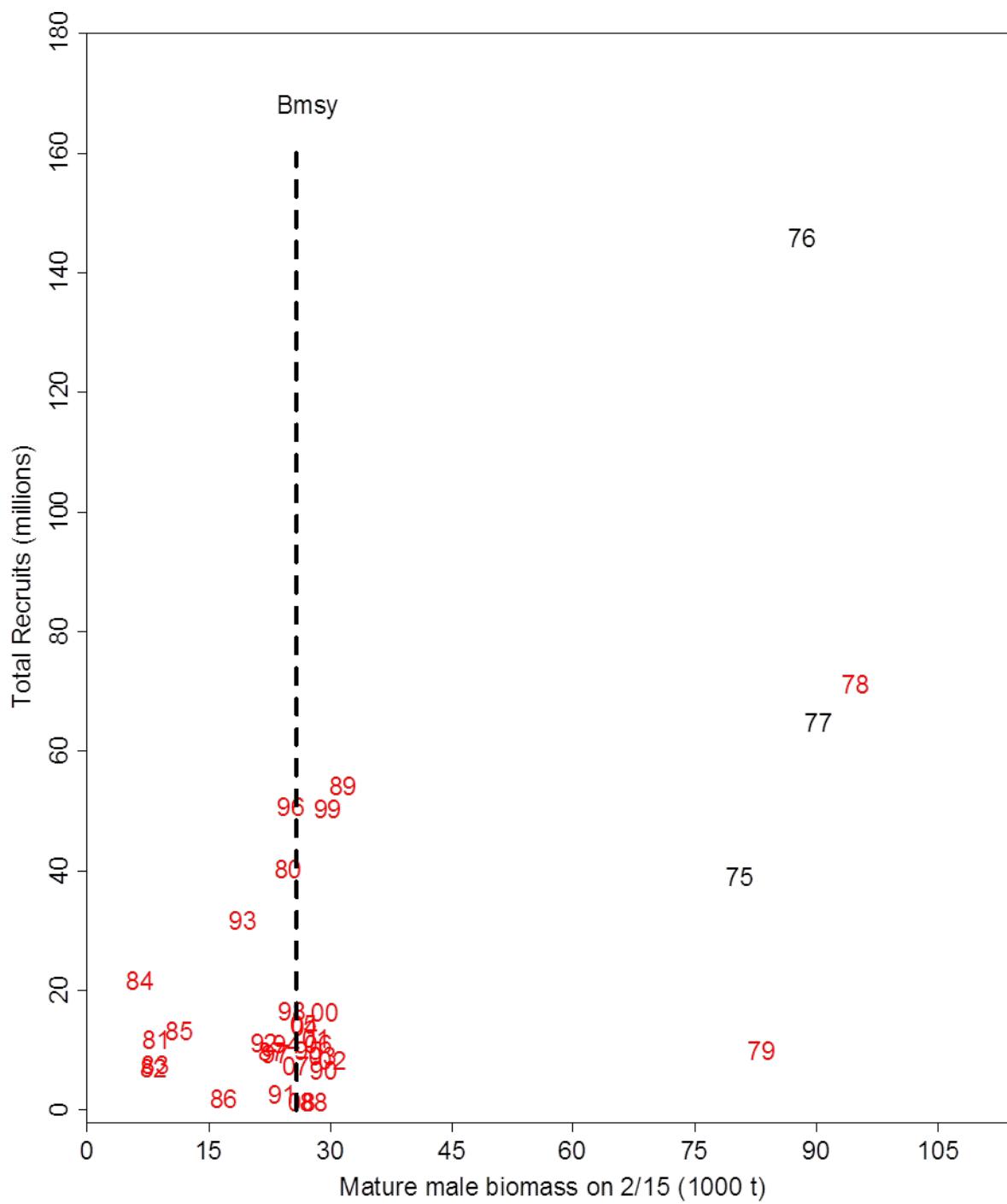
# Scenario 1



## Scenario 1



# Scenario 1



# Estimated biological reference points and OFLs

(Based on the B35% estimated from the average male recruitment during 1984-2014, and ABC = 0.9\*OFL)

	Scenario 1		Scenario 2	
	1000t	Mill. lbs	1000t	Mill. lbs
B <sub>35%</sub>	25.703	56.665	23.359	51.498
F <sub>35%</sub>	0.29		0.30	
MMB <sub>2014</sub>	24.687	54.443	23.808	52.488
OFL <sub>2014</sub>	6.820	15.036	7.125	15.709
ABC <sub>2014</sub>	6.138	13.532	6.413	14.138

# Thanks



Double bag experiment  
and BSFRF survey for  
estimating capture  
probability

